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HEADQUARTERS

AIR FORCE SPECIAL WEAPONS CENTER

AIR RESEARCH AND DEVELOPMENT COMMAND

KIRTLAND AIR FORCE BASE, NEW MEXICO

Volume II

HUMAN FACTORS HANDBOOK

For Design of Testing and Monitoring Ground Support Equipment

by

George L. Murphy

Paul H. Newman

AMERICAN INSTITUTE FOR RESEARCH

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ABSTRACT

This handbook, Volume II in a series of three, has been prepared for designers of Testing and Monitoring Equipment used to support airborne weapons. Volume I is concerned with Transporting, Positioning, and Lifting Equipment; Volume III, with Protective and Storage Equipment. The three volumes are intended as guides for the military or industrial designer who translates an idea into drawings and eventually into actual equipment. They may also be useful to persons preparing specifications for proposed equipment or evaluating such specifications. Each volume is meant to be self-sufficient and for this reason some duplication of material from book to book has been judged necessary.

The chapter headings in Tables of Contents show in general the types of equipment discussed in each handbook. An Index in each book contains page references to aid the user in locating information on specific components. A selected bibliography has also been included in each book, for use if detailed source information is needed beyond that found in the handbook.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

CAREY L. O'BRYAN, JR.
Colonel USAF
Chief of Staff

FOREWORD

The term "human engineering" has been used in recent years to characterize the work of specialists who assist engineers in the design of equipment for human use. Equipment has always been designed for human use, but only with the advent of modern weapon systems has it become apparent that designing for human use implies a need for specialized knowledge of human capabilities and limitations. Whether one considers the term "human engineering" an apt title or a misnomer--and there will be controversy over this for years to come--modern weaponry has underscored the requirement for the inputs this young and growing discipline can make to equipment design. Given the size, complexity, and costs of the weapon systems of today and tomorrow, it has become essential that equipment be so designed as to minimize the likelihood of human error in operation and maintenance, to minimize needs for training and special skills, and to maximize safety and efficiency.

To meet these needs, human engineers have striven to develop "working principles" which embody the best recommendations they can make to engineers responsible for design and development. These "working principles" have come from knowledge of man's mental and physical capacities, from experimental studies of human responses to various types of stimulus conditions, and from observations of man as a functional component in an operational system.

There is a vast amount of literature available to the design engineer who wishes to incorporate human factors principles into his equipment design, but searching this literature constantly would place an unreasonable burden on the engineer. The literature should be summarized for him and made available in a form readily usable and meaningful. That is the purpose of this handbook and its two companion volumes.

Future investigations can be expected to yield more information on human behavior pertinent to the design of ground support equipment, and to confirm or force revision of some working principles which are presently best guesses. Periodic review of these handbooks is recommended so that new information can be incorporated as it becomes available.

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CHAPTER I.

HAND HELD, PORTABLE, AND CONSOLE TYPE TESTERS

In this chapter human factors design recommendations are given for the three basic types of testers. Hand held testers are very light, small instruments ordinarily capable of being held and operated by one hand. Portable testers are larger and heavier, but can be carried from place to place, usually by one man. Console type testers are large semi-permanent fixtures, made up of a number of smaller units or sub-assemblies. The individual units which make up a console are similar in many ways to portable testers. Thus most of the recommendations in Section C regarding units are also applicable to portable testers.

Obviously the three types of testers have much in common. Recommendations concerning features which are common to more than one of the types of testers are contained in succeeding chapters. Controls, for example, are discussed in Chapter Three, and Displays in Chapter Four. Chapter Five contains recommendations on instrument panel layout.

SECTION A. HAND HELD TESTERS

1. SPECIFY HAND HELD TESTERS ONLY FOR FAIRLY SIMPLE TESTING TASKS.

a. Use only when one or at the most, two functions are to be measured.

b. Hand held testers should be used when the operator must take measurements at fairly inaccessible locations, such as in an aircraft bomb bay after the weapon has been loaded.

2. SIZE, WEIGHT, AND SHAPE

a. Hand held testers should not weigh more than three pounds maximum and should be capable of being held in one hand.

b. Tester should be shaped to fit operator's hand.

c. Serrate or ridge the underside of tester to prevent it slipping out of operator's hand.

Figure 1. Hand Held Tester.

3. DESIGN HAND HELD TESTERS SO THAT OPERATOR MAY USE ONE OR BOTH OF HIS HANDS FOR OTHER TASKS WHEN NECESSARY.

a. Where possible design tester so that operator can hold and operate it with the same hand.

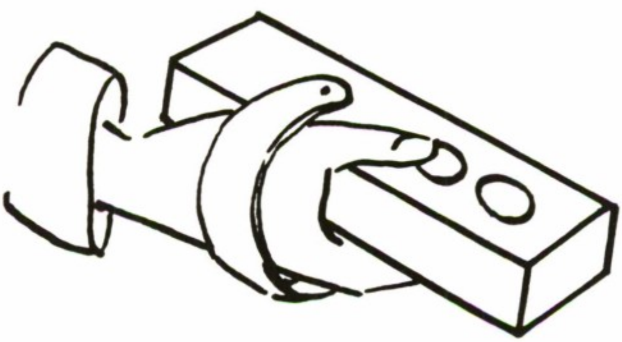


Figure 2

b. Provide a grip on the underside of tester through which the hand can be inserted. This will reduce probability of dropping the tester and will eliminate necessity for holding tester with other hand.

c. Equip tester with a string or strap which operator can hang around his neck so that when not in use the tester can hang free and permit use of both hands for other tasks.

4. HAND HELD TESTERS SHOULD BE AS SIMPLE FUNCTIONALLY AS POSSIBLE.

a. Tester should be self-powered, and not require attachment to an electrical outlet.

If battery powered, tester should be designed to give the operator some indication of when to change batteries. One way of doing this is to have an insert on which is printed "Return tester to Maintenance Shop before (date) for battery change."

b. Indicator should be of the simple go/no-go type, with a light to indicate out of tolerance conditions.

If a meter is necessary, tolerance zones should be color coded.

SECTION B. PORTABLE TESTERS

1. SPECIFY PORTABLE TESTERS WHEN PORTABILITY IS A REQUIREMENT AND HAND HELD TESTER WOULD NOT BE ADEQUATE.

a. Use when number or complexity of functions to be tested would make hand held tester too heavy or bulky.

b. Specify portable testers when equipment to be tested will not be located at a permanent testing installation.

c. Portable test equipment should be used when a number of pieces of equipment have to be tested and they are separated geographically.

2. SIZE, WEIGHT, AND SHAPE

a. To facilitate one-man handling, keep weight of portable testers under 30 pounds.

(1) If tester must weigh more than 30 pounds, consider providing a stand equipped with wheels or casters.

(2) When weight is in excess of 100 pounds, it is imperative that a wheeled base be provided.

b. For one-man handling, limit width of portable testers to 18 inches.

c. Conventional block or square shape is recommended for ease of storage.

3. PROVIDE ADEQUATE HANDLES AND GRIPS SO THAT TESTER CAN BE EASILY CARRIED.

a. If tester will be carried by one man, place handle at the top and directly above the center of gravity.

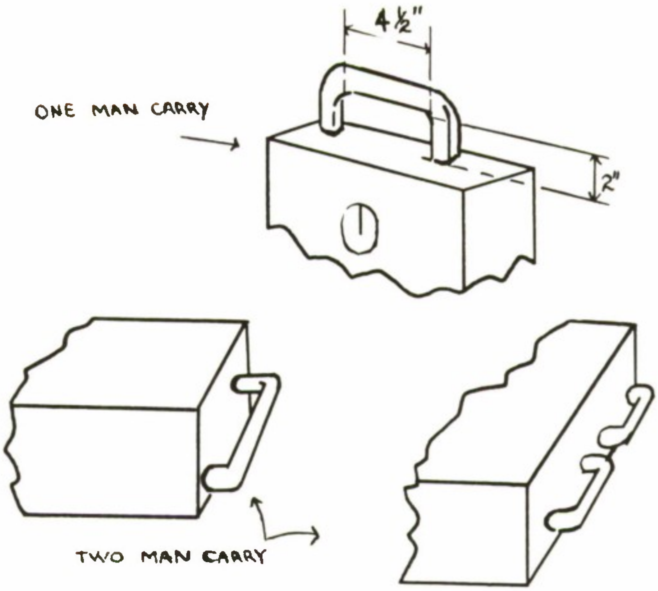


Figure 3. Tester Handles.

b. If tester will be carried by two men, place handles at both ends and above the center of gravity.

Provide two larger or four standard handles for two-man carry.

c. Handles should be strong enough to bear the weight of the tester.

d. Make handles of sufficient size and shape to avoid operator discomfort.

(1) Avoid sharp or thin edges.

(2) Handles should be at least 4½ inches long and 2 inches deep if they will be used only with the bare hand. Increase both dimensions at least ½ inch for use with gloves.

e. To conserve storage space, consider the use of recessed or hinged handles on portable test equipment.

f. Provide an adjustable harness or sling to facilitate carrying testers.

g. If tester has a removable cover, provide handles or grips on the sides of the tester for carrying it when cover is not attached.

4. DESIGN OF COVERS AND LIDS

a. Covers should be easy to open and close.

(1) Use rounded corners and edges for safety.

(2) Provide positive latch so that cover will not open inadvertently when tester is being carried.

b. Hinged, permanently attached covers are recommended for portable testers.

If tester must have a removable cover it should be labeled with the same identification as the tester.

c. Lids and covers may be designed to provide storage space for Technical Orders and removable accessory items such as adapters and leads.

d. Cover or lid may contain display tables and instruction lists.

5. MAKE OPERATION OF TESTER SIMPLE AND RELIABLE UNDER ALL EXPECTED ENVIRONMENTAL CONDITIONS.

a. Make warm-up and starting procedures simple and rapid.

b. Provide for go/no-go indications where possible.

c. Instructions should be easily available to operator.

(1) Print instructions on metal plate and attach to tester panel, to tester lid, or on a sliding metal drawer.

(2) Consider the use of a roller type display for presenting instructions.

d. Clearly label on tester connectors what type electrical source should be used.

e. Provide panel lighting so that tester can be used under conditions of low illumination and high illumination.

f. Design stands on which tester can be placed while being used.

SECTION C. CONSOLE TYPE TESTERS

This category includes all permanent type, nonportable testing and monitoring equipment. It includes equipment located in a fixed installation as well as van mounted test equipment. A console type tester may sometimes be merely one large tester. The usual console type tester, however, is a combination of many individual units.

GENERAL CONFIGURATION

1. USE MODULAR DESIGN TO THE EXTENT POSSIBLE.

a. Off the shelf modular units should be used whenever they are available.

b. Design equipment so that consoles can be converted from one function to another by the replacement of modules.

c. Do not "marry" units to each other. It should be possible to check and adjust each unit separately and then connect the units together into a total or functioning system with little or no additional adjustment required.

2. ARRANGE UNITS AND COMPONENTS WITHIN CONSOLE FOR EASE OF OPERATION AND MAINTENANCE.

a. Arrange units so that devices which must be manipulated during normal operations are accessible by reaching without stooping, stretching, or use of auxiliary platforms. Recommended range of heights from the floor for the standing operator is 3 to 6 feet.

b. Units should be laid out so that a minimum of moving from position to position during system checking in the installation is necessary.

Units maintained by the same technician should be grouped.

c. Mount components in an orderly array on a two dimensional surface.

Provide sufficient space for technician to use test probes, soldering irons, and other required tools without difficulty. (See page 8 for recommended dimensions).

d. Units which require frequent visual inspection should be installed in positions where they can be seen easily without removing panels, covers, and/or other units.

e. Arrange units so that no other equipment has to be removed to gain access to them for inspection or removal.

Units should not be stacked, but if necessary to stack them because of space limitations, the unit requiring least frequent access should be placed on the bottom or in the back.

f. Arrange units so that technician does not have to reach out for heavy units.

g. Structural members of consoles or units should not prevent access to components.

(1) Do not permit bulkheads, brackets, or other units to interfere with removal.

(2) Units should not be placed behind items which are difficult to remove unless this serves some function such as protecting the unit.

h. Locate units so they can be removed from console along a straight or moderately curved line rather than through an angle.

3. ALLOW SUFFICIENT TOLERANCES FOR ALL EXPECTED CONDITIONS.

a. Do not design in closer tolerances than are necessary.

b. Allow wide range of tolerances for items subject to extremes of adverse operational conditions.

c. Tolerances should be sufficient to accommodate various sizes and characteristics of any one type of component such as electron tubes, resistors, and indicators. Figure 4 illustrates the result of failure to allow sufficient tolerance in cover design.

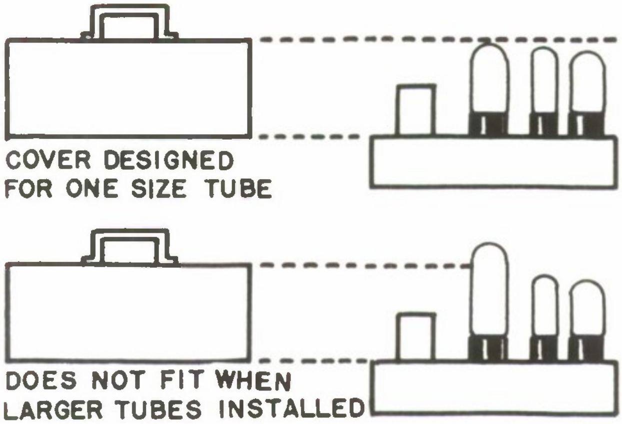


Figure 4

ACCESSES AND ACCESSIBILITY

Provide accesses in console panels so that maintenance personnel will not have to remove cases or covers, open fittings or dismantle components to perform frequent maintenance operations.

4. TYPE OF ACCESS WILL BE DICTATED BY THE OPERATION TO BE PERFORMED.

a. For the insertion of tools, test leads and service equipment, the preferred type of access is an opening with no cover. If dirt and moisture are a problem, use a sliding or hinged door. If a door will not meet stress requirements, or if available space will not permit hinged accesses, use cover plates with captive, quick disconnect, one-hand operated fasteners.

(1) Hinged door accesses should open downward and be provided with thumb operated quick release latches. Such latches should have large enough operating surfaces to prevent physical injuries or discomfort.

(2) If screws are necessary on cover plates because of stress requirements, use a few large captive screws rather than many small ones.

b. For visual inspection accesses use an opening with no cover, or, if this is not feasible, a plastic or break-resistant glass window.

Plastic is preferred over glass, but may sometimes not be acceptable because of the possibility of physical wear or contact with solvents causing optical distortion.

c. When the operation to be performed through an access must be observed by the technician, one large access through which both visibility and access can be provided is preferred.

Where complex tasks must be performed through small accesses past wrist insertion, an access door and a separate window should be provided to enable the technician to see what he is doing inside the access.

5. ACCESS SHOULD BE LABELED FOR EASY IDENTIFICATION.

a. Label should identify items which are accessible through the access and auxiliary equipment to be used at the access.

b. Indicate adjacent to each access the recommended periods, either in calendar or operating time, when operations should be performed through the access.

c. Where tubes or plugs must be inserted through small accesses, provide an external indication of the position for pin insertion.

d. Identify the access by a symbol (letter, number, or combination of letters and numbers) to avoid confusion of that access with other accesses and to allow clear reference to the access in job instructions.

6. LOCATE ACCESSES TO PERMIT MAXIMUM CONVENIENCE IN PERFORMING JOB PROCEDURES.

a. Placement of accesses will be dictated by the position of internal components, the way in which they must be installed, and operations a technician will have to perform through a given access.

b. Determine which faces of equipment will be accessible in normal installation and place access on one of them.

c. Removal of any unit or component should not require opening more than one access.

7. SIZE AND SHAPE OF ACCESSES

a. Accesses should be large enough to accommodate the objects to be inserted, or to permit necessary visual inspection, but dimensions should be no larger than necessary.

(1) For inserting a miniature vacuum tube held between thumb and first two fingers a 2 inch square aperture should be provided.

(2) When a large vacuum tube (1-3/8 inch base by 4½ inch height) is to be inserted or if technician must install or tighten a 14 conductor cannon plug with outside diameter of 1-7/8 inches, access should be 4 inches square.

(3) For inserting and using an 8 inch screwdriver with a 1 inch diameter handle, provide a 3¾ inch square access.

(4) Additional access dimensions which may be useful under some conditions, can be found in Chapter 1 of Volume I (Transporting, Positioning, and Lifting Handbook).

b. Generally the shape of accesses should be designed to permit easy passage of components and tools.

(1) Consideration should be given to using different shaped accesses for quick identification when there are a number of accesses from which one must be selected.

(2) If there is only one right way to attach removable access plates and incorrect attachment can lead to equipment damage, the access plate should be shaped so that it can be attached only in the correct way.

8. MOUNT UNITS SO THAT THEY ARE EASILY ACCESSIBLE AND REMOVABLE.

a. Mount units on slide out racks from which they can be easily lifted in preference to attaching them with fasteners.

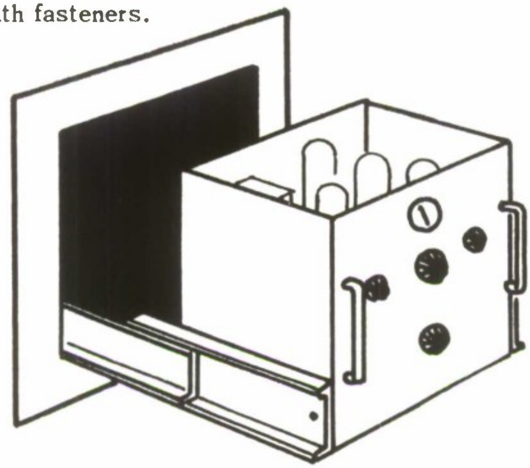


Figure 5. Slide out rack.

(1) Equip mounting racks with limit stops to prevent dropping of units.

(2) All units should be identified on the front panel by a number or other designation so they can be replaced in the proper rack.

b. Mount units independently to the housing rather than attaching them to each other.

c. Provide replaceable units and assemblies with plug-in rather than solder connections.

d. Hinge mounted units which must have access to the back should be free to open their full distance and remain open without being held.

e. Use pilot guides, slides, and guide pins to facilitate replacement of heavy units or units which have inaccessible mounting positions.

9. MOUNTING FASTENERS SHOULD BE DESIGNED TO FACILITATE MOUNTING AND DISMOUNTING OF UNITS.

a. Hand operated fasteners should be used for mounting units wherever possible. Fasteners requiring standard hand tools are acceptable, but those requiring special tools should be avoided.

Fasteners should be capable of being fastened or unfastened in a maximum of one complete turn.

b. Heads of mounting bolts and fasteners should be placed on a surface adjacent to the technician's work space.

c. The number of different sizes and types of screws, bolts, and fasteners used on a particular piece of equipment should be kept to a minimum.

Make mounting screws interchangeable, but if this is not possible, screws with different threads should be of different sizes.

d. Do not use more than four screws for mounting a major unit in an installation unless required by stress considerations.

e. Captive mounting bolts and screws should be used in situations where the dropping of these small items into the equipment would create a difficult removal problem or might cause damage to equipment.

f. Provide technician a means of differentiating mounting bolts and fasteners from other fasteners.

(1) Mounting screws and bolts can be made a different color from other screws and bolts.

(2) An "M" or other symbol might be embossed on the heads of mounting bolts.

g. To facilitate mounting of units with the common hand tools which might be available, design mounting bolts with a deep internal slot and an external hex head so that technician can use either a screwdriver or wrench.

This will permit wrench to be used on jammed bolts or those requiring high torque, and will reduce the need for driving out bolts with damaged slots.

HANDLING OF UNITS

10. KEEP UNITS LIGHT AND SMALL ENOUGH FOR ONE MAN HANDLING.

a. Units should not weigh more than 30 pounds or be more than 18 inches wide.

b. If units cannot be readily handled by one man, provide hoisting facilities.

Design of such units should incorporate lifting lugs for the attachment of hoist equipment.

c. Make provisions for auxiliary stands on which units can be supported while they are being removed or installed.

d. To aid in handling removable units, make bolts, cables, wave guides, hoses, and other protrusions removable.

11. PROVIDE ADEQUATE HANDLES AND GRIPS ON UNITS.

a. If unit weighs more than 10 pounds, it should have convenient handles to assist in removal, replacement, or carrying.

(1) Handles should be at least 4½ inches wide and allow finger clearance of at least 2 inches.

(2) Do not place handles in position where they can catch on other units, wiring, or structural menbers. This hazard can be minimized by hinging or recessing handles.

b. If unit weighs less than 10 pounds and is difficult to grasp, remove or hold, it should also be designed with handles.

c. Provide recessed handles or grips near the back of heavy units to facilitate their removal from chassis.

d. Avoid sharp or thin edges on handles and grips.

COVERS AND CASES

12. Design cases that can be lifted off units, rather than units lifting out of cases.

13. Use hinged and tongue-and-slot catches on covers to minimize the number of fasteners needed.

14. Covers should be designed with rounded corners and edges for safety.

15. Covers and cases should have their own stock numbers in the event they must be replaced separately, but should be identified with the unit to which they are attached.

CHAPTER II.

GENERAL CONSIDERATIONS IN THE DESIGN OF TEST EQUIPMENT

SECTION A. ELECTRICAL CONNECTORS

To perform its function most test equipment will be connected to a piece of prime equipment or to another tester. Recommendations in this section are concerned with the human factors problems in making connections both to receptacles and to test points.

CABLES, ADAPTERS AND RECEPTACLES

1. REDUCE THE NUMBER OF NECESSARY CONNECTIONS WHEREVER POSSIBLE.

   a. Whenever feasible, leads should be permanently attached to the test equipment.

   b. Use selector switches on test equipment rather than plug-in connections (if the effects of switching, i.e., introduction of noise, will not degrade desired information).

2. CLEARLY IDENTIFY ALL ELEMENTS USED IN MAKING CONNECTIONS.

   a. Test leads, adapters, and receptacles should be clearly labeled.

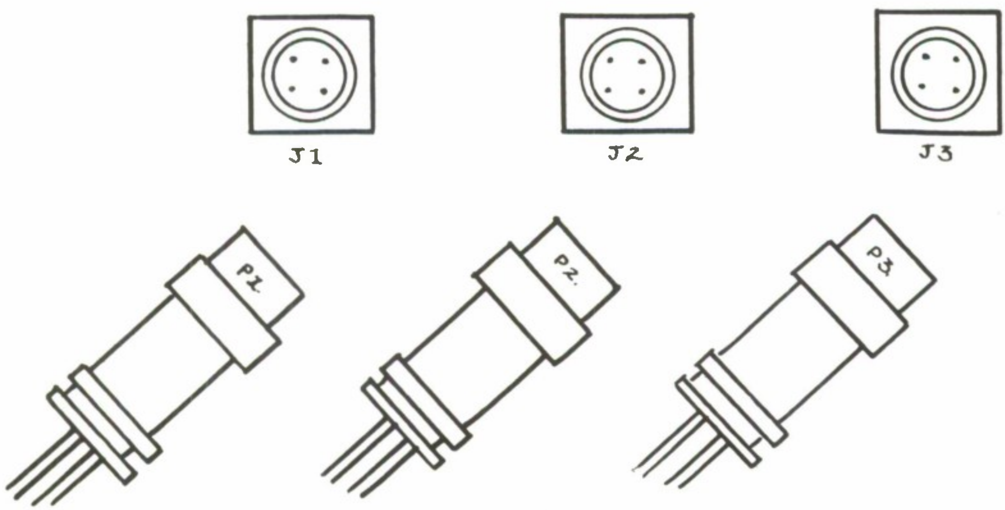


Figure 6

   Label plugs and receptacles with corresponding numbers. In Figure 6, for instance, P1 plugs into J1, P2 into J2, etc.

   b. Identify each pin on all plugs.

   c. Label each plug in such a way that it can easily be identified.

   Do not use labels that will wear off.

d. Check points, adjustment points, cable-end connections, and/or labels should be in full view of the technician who will make connections or adjustments at that point.

3. MAKE CONNECTIONS EASY AND ERROR-FREE.

a. Design wiring, tubing and control cables so that incorrect assembly is impossible.

(1) Use keys and keyways to prevent misalignment.

(2) Provide plugs and receptacles with aligning pins or other alignment devices.

(3) Aligning pins on plugs should project beyond the electrical pins.

(4) Make the various plugs and receptacles used with a particular piece of test equipment different sizes.

(5) As an aid in alignment, plugs and receptacles should have painted stripes, arrows, or other indications to show proper position of keys or aligning pins for proper insertion.

b. If there is a possibility of incorrect connections, color code plugs and receptacles.

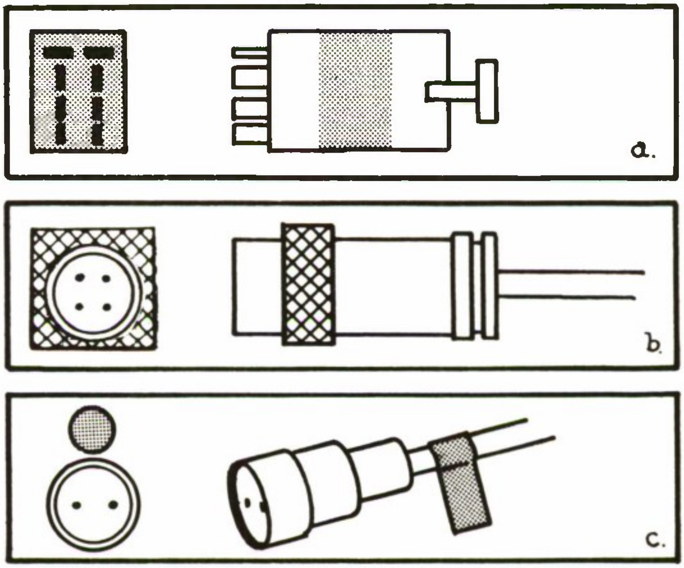


Figure 7

Color the face of receptacles (Figure 7a), receptacle bases (Figure 7b) or an area immediately contiguous to the receptacle (Figure 7c). Place matching colors on a stripe around the plug (Figure 7a), the tightening rings (Figure 7b), or on an identifying band which has both cable number and color on it (Figure 7c).

c. In designing cable connections, specify a few cables with many pronged plugs rather than many cables and plugs with fewer prongs.

d. Provide for easy passage of replacement cables with their attached connectors through walls, bulkheads, and accesses.

e. Do not require removal of sections of equipment for attachment of cables and leads.

f. Locate connectors far enough apart so that they can be grasped firmly for connection and disconnection. Separation distance will depend on size of connectors and force required to tighten or loosen them.

g. Connectors should be of the quick disconnect type.

(1) Leads should require no more than a fraction of a turn for attachment to prime equipment receptacles.

(2) Plugs should have a self-locking safety catch rather than requiring safety wiring. If safety wiring is a requirement, design holes and slots for most efficient and rapid attachment of safety wire.

h. Use plug-in rather than solder connections.

i. Do not require operator to assume awkward positions to make connections.

Place receptacles on side of a tester facing free work space.

4. DESIGN CONNECTIONS TO AVOID PERSONNEL INJURY OR EQUIPMENT DAMAGE.

a. Disconnected plugs and connections should not expose "hot" leads.

b. Plugs and leads should not be capable of transmitting stored charges when being disconnected.

c. Test leads should be located where they cannot be pinched or walked on.

d. Lead pins and plugs should be designed strong enough so that they will not be damaged by rough use.

e. Consider the use of a clear plastic covering to insulate leads and cables so that breaks in internal wiring can readily be seen.

f. In designing cables for connecting tester to prime equipment, make the cables long enough so that tester can be removed from high noise level area or area in which there is danger.

5. ADAPTERS SHOULD BE ELIMINATED BY INCORPORATING THEM IN THE BODY OF THE TEST EQUIPMENT.

If adapters must be used, make them a part of the test equipment removable items.

TEST AND ADJUSTMENT POINTS

For trouble shooting of electronics units, it is frequently desirable to provide points in the circuit at which voltages can be sampled, and in some cases points at which voltages can be adjusted. Sampling of voltages will ordinarily be done by attaching a probe or clip to the test point and reading the voltage on a test instrument. Adjustments will usually be of the screw-driver type.

6. TEST POINTS SHOULD BE LOCATED IN SUCH A WAY THAT THEY ARE EASILY ACCESSIBLE.

a. Test points which are frequently used should be brought to the front panel of the equipment.

b. If test points are located internally, access to them should not be blocked by other component or wiring.

(1) Provide adequate space for technician to work.

(2) Do not locate test points in immediate area of high voltage - leave more than a hand's width (at least 4 inches) separation between the test point and the nearest high voltage component.

c. When locating test points on a particular chassis, consider the total equipment in which it will be installed and provide for easy accessibility.

(1) Cluster internal test points around the portion of the unit most accessible when installed.

(2) Do not require technician to remove panels to gain access to test points.

7. LOCATE TEST POINTS AND ADJUSTMENT POINTS FOR MOST EFFICIENT TESTING AND ADJUSTMENT.

a. Plan location of test points, rather than locating them randomly throughout the system.

b. Place test points in proper functional location (tied into circuit where the technician needs to sample signals).

c. Locate adjustment points in close proximity to their associated test points.

d. Group all test points used by a particular type of technician on a single accessible test panel.

When possible, locate test panels on an outside surface of the equipment 4 to 5½ feet from the floor on which technician will stand.

e. Do not concentrate test points in one place unless such concentration serves some useful purpose.

f. For replaceable units make test points available for each input and output.

8. LABEL TEST POINTS FOR EASY IDENTIFICATION AND USE.

a. Paint test points an outstanding color so they can be easily located.

b. Label at test point should indicate unit whose output is available, in-tolerance signal and tolerance limits, and should be identified by a symbol pertinent to only that particular test point. Symbol should correspond to that on schematics.

c. Leads to be used with a particular test point should be color coded to give technician a better idea of which test point he is tapping.

d. When test point is located internally, its location should be indicated on an access plate on the outside of the tester.

9. DESIGN FOR EASY ATTACHMENT OF LEADS TO TEST POINTS.

a. No more than one full turn should be required to attach test equipment to a test point.

b. When probes are used to measure output at test point, provide them with quick-disconnect fasteners so that technician's hands will be free.

SECTION B.

SIMPLICITY OF OPERATION AND MAINTENANCE

> The reliability of the operator or technician can be increased by designing the equipment to be easily operated, error free, and able to withstand hard use.

1. MAKE EQUIPMENT SIMPLE TO OPERATE AND PROVIDE SELF-CHECKING AND CALIBRATION FEATURES.

a. Design test equipment for one man operation, thus eliminating the need for coordination of tasks.

b. Provide a simple method to put test equipment into calibration.

Equipment should be equipped with a go/no-go indicator or simple check to determine whether tester is malfunctioning or out of calibration.

c. A warm-up indicator should be provided if applicable. Required warm-up time should be clearly indicated near warm-up switch if no visual signal is provided.

d. Tester should incorporate a simple check for testing accuracy of results.

e. The number and complexity of steps required for operation should be kept to a minimum.

f. To avoid necessity for operators to refer to a manual, designer should attach printed instructions to tester.

(1) Attach conversion tables to test equipment when necessary. Make standards and tolerances explicit.

(2) Purpose of tester and special cautions in its use should be clearly indicated in attached instructions.

(3) Provide set-up procedures on an instruction card attached to equipment.

g. Do not require tests necessitating quantitative readings and adjustments by operating personnel. Limit adjustments to those essential and provide for them to be made by means of equipment of the "low-go-high" type, furnishing information by qualitative positive signaling devices, such as color coded signals, zero center meters or similar means of indication.

2. DESIGN EQUIPMENT TO EITHER PREVENT OPERATOR FROM MAKING ERRORS OR WARN HIM OF HIS ERRORS.

a. Clearly label on component or equipment whether to be used with alternating or direct current.

b. Provide circuit breakers, on all testers, to safeguard against damage if the wrong switch or jack position is used.

c. Incorporate "fail-safe" features into equipment design to minimize danger to operator and equipment should failure occur.

d. Design components so they cannot be installed in the wrong way.

e. Specify regularly stocked components and units.

f. Insure that if components are interchangeable physically that they are also functionally interchangeable.

3. PROTECT AGAINST DAMAGE TO TESTERS OR LOSS OF TESTER COMPONENTS.

a. Test equipment should be built to be as rugged as the conditions of its use will make necessary, that is, equipment to be used in the field should be more rugged than that built for laboratory use.

b. Attach small removable parts such as pins, caps, and covers to main body of equipment by small chains to prevent their loss.

c. Design controls, dials, and adjustments to prevent misalignment due to vibration, service use, or accidental contact.

d. Use lock washers, or other restraining measures to prevent bolts, nuts, and other components from vibrating loose.

4. PROVIDE SAFEGUARDS AGAINST EQUIPMENT DAMAGE FROM INADVERTENT HUMAN ERROR.

a. Protect equipment against possibility of operators turning on full power before tubes are warmed up.

(1) Make warm-up procedures explicit.

(2) Provide warm-up indicators.

b. Design equipment with devices to insure that equipment is turned off when testing is completed.

(1) Power switches should shut off automatically when tester lid is closed.

(2) Include on tester panel a warning signal to indicate that power is ON.

c. Design controls to prevent equipment damage if operated at the wrong time or in the wrong manner.

d. Locate delicate components where they will not be damaged while the unit is being worked on.

SECTION C. SAFETY CONSIDERATIONS

1. DESIGN EQUIPMENT SO THAT INDIVIDUALS HANDLING IT ARE PROTECTED FROM SHARP EDGES, POINTS, HEAT, AND ELECTRICAL CHARGES.

a. Avoid sharp edges, projections and hinged devices with hazardous characteristics.

b. Shield all moving and cutting parts near controls.

c. Provide covers of rubber or other appropriate material over protrusions, rails, and corners with which operators may come in contact.

d. Heat producing equipment should be located and shielded to avoid discomfort to the operator.

e. Design equipment interlock switches to break electrical circuit when removal of a cover or panel exposes high voltage areas.

f. Do not locate internal controls close to dangerous voltages or acids.

(1) Insulate exposed shock sources that must be located near controls. Locate controls in such a way that movements do not cause contact with equipment that could cause injury. Insulate or guard high voltage areas and high current switching devices if there is danger of personnel contacting them.

(2) Do not route power cables through switches which personnel in remote locations are likely to switch off or on inadvertently while the equipment is being checked.

g. If injury potential must exist, provide adequate warning placards.

CHAPTER III. CONTROLS

Controls are the means by which an operator effects changes in the state or condition of equipment. Generally controls include any objects which he manipulates with his hands or his feet. Since foot controls are seldom used in testing and monitoring equipment, this chapter does not include recommendations about them. For those designers faced with the problem of designing foot controls, information can be found in Volume I of this series of handbooks.

Each section of this chapter contains information specific to a particular type of control: Knobs, Selector Switches, Cranks, Toggle Switches, Levers, and Push Buttons. The designer must first, however, decide what type of control he will use for a particular function. This decision should be based on an analysis of the operations to be performed and should consider the particular control function in relation to all other tasks which the operator will be required to perform. Selection of controls will also depend to some extent on availability of space, since some controls are more economical of space than others.

SECTION A. KNOBS

1. SPECIFY KNOBS UNDER THE FOLLOWING CONDITIONS:

a. When precise, accurate adjustment of a continuous variable is required.

b. When little force is required.

c. When conservation of panel space is not critical.

d. When coding by color, size, or shape is desired.

SIZE AND SHAPE OF KNOBS

2. IN DETERMINING SIZE OF KNOBS, CONSIDER MANNER OF OPERATION AND AVAILABLE PANEL SPACE.

a. In general, knobs which are grasped by the fingers or palm of the hand should be no more than 3 inches in diameter.

(1) If space is at a premium, knobs to be operated by fingertip grasp may be as small as 3/8 inch diameter. However, a minimum of 1 inch is recommended.

(2) Knobs to be operated by palm grasp should be no smaller than 1½ inches in diameter.

b. Where knobs are used for continuous movement under light loads, their diameter should be 1 to 2 inches.

Under heavy loads knob diameter may increase up to 4 inches, depending on the load.

c. When rapid (though perhaps less accurate and less controlled) adjustment is required, specify small diameter rather than large diameter knobs, keeping in mind that as knob diameter is decreased, resistance must also be decreased.

3. DEPTH OF KNOBS MAY RANGE FROM ONE-HALF TO ONE INCH.

a. Knobs less than ¾ inches in depth should be knurled to prevent slipping.

b. Serrate knobs of more than ¾ inches in depth to prevent slipping.

4. SHAPE OF KNOBS SHOULD BE DETERMINED BY FUNCTION AND USE.

a. All knobs which perform the same function should have the same shape.

b. For knobs which must be recognized by touch alone, select shapes in accordance with recommendations contained in Chapter 5.

c. Knob shapes similar to those shown in Figure 8 are recommended when more than one full turn is required.

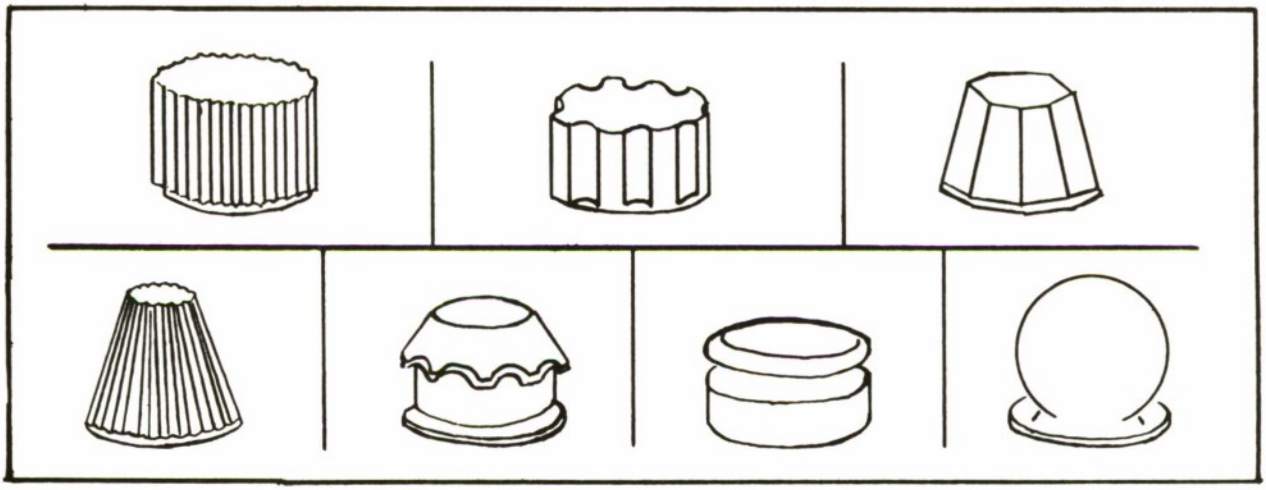


Figure 8

d. Figure 9 illustrates knob shapes recommended when less than one full turn is required.

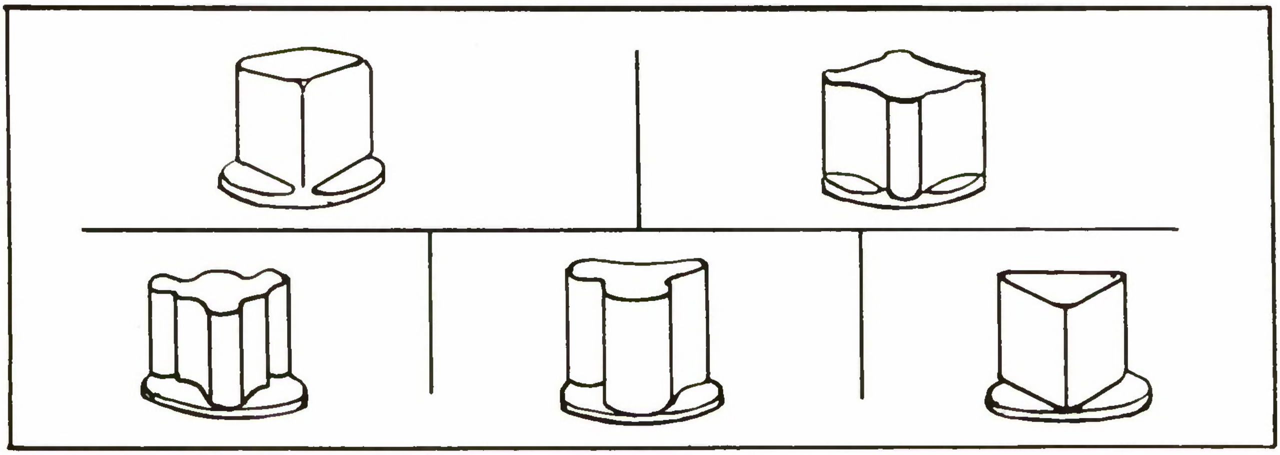


Figure 9

5. BAR AND POINTER TYPE KNOBS

a. Use bar and pointer knobs for discrete positioning operations.

b. Specify pointer type knobs to indicate a marking or to indicate relative position from a fixed point.

c. Avoid the use of pointer knobs when rotation is more than 360 degrees.

d. Specify bar or pointer knobs when only 2 or 3 settings are used.

GANGED KNOBS

6. CONDITIONS UNDER WHICH CONCENTRICALLY GANGED KNOBS SHOULD BE USED.

a. When the operations to be performed are sequential, or if going from one knob to the next is often done without visual reference.

(1) When concentric knobs are used sequentially, the front (smallest) knob should be used first, the back (largest) last.

(2) Coarse settings should be made with the small inner knob and fine adjustments with the larger outer knob.

b. If inadvertent operation of adjacent knobs or small delays are not important.

Addition of shields on ganged knobs will reduce errors made on adjacent knobs.

c. In cases where knobs of larger diameter are required, regardless of arrangement.

d. When detent knobs or combinations of detent and continuous rotation knobs are used.

e. If space behind the display must be conserved.

7. DO NOT USE CONCENTRICALLY GANGED KNOBS WHEN

a. The knobs are in continuous rotation or under low friction.

b. Frequent inadvertent operations of adjacent knobs cannot be tolerated.

c. The only reason for ganging is to save panel space, since individual knobs generally do not take up any more space than ganged knobs.

KNOB CONTROL FORCES

8. Design control knobs with a minimum of resistance, but incorporate sufficient resistance to guard against accidental or inadvertent movement.

9. Maximum resistance for fingertip operation of knobs under 1 inch in diameter should be 4½ inch-ounces.

10. For fingertip operation of knobs larger than 1 inch in diameter maximum resistance is 6 inch-ounces.

11. When a knob is used for making discrete settings, the accuracy of settings may be enhanced by increasing the holding action of the detent.

This will result, however, in a slower selection speed.

KNOB MOVEMENT

12. When a knob is used for making fine adjustments on a scale there should be between 60 and 80 degrees movement from just detectable misalignment in one direction to just detectable misalignment in the other.

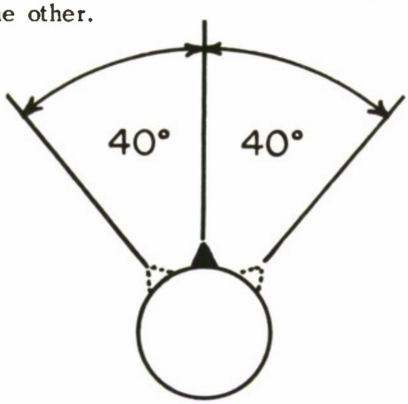


Figure 10. Knob Movement.

13. Design an audible click into controls which are used for discrete settings so that operator will have an additional cue to accurate setting of the knob.

14. See Chapter IV, Section F, for additional recommendations on knob movements.

SECTION B. SELECTOR SWITCHES

1. Specify rotary selector switches for multiple positioning and for selection of 3 or more discrete positions.

On fixed scales the selector switch should be a moving pointer type knob (generally a bar type with a tapered tip). (See Figure 11.)

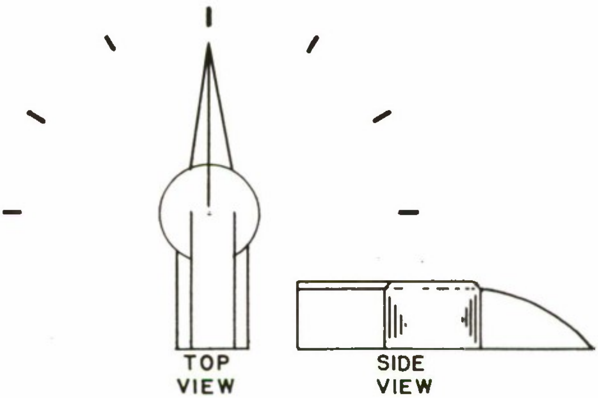


Figure 11

2. Design equipment with a selector switch rather than requiring cable connections and disconnections for a number of test conditions.

3. Use selector switches to conserve panel space.

SWITCH SIZE

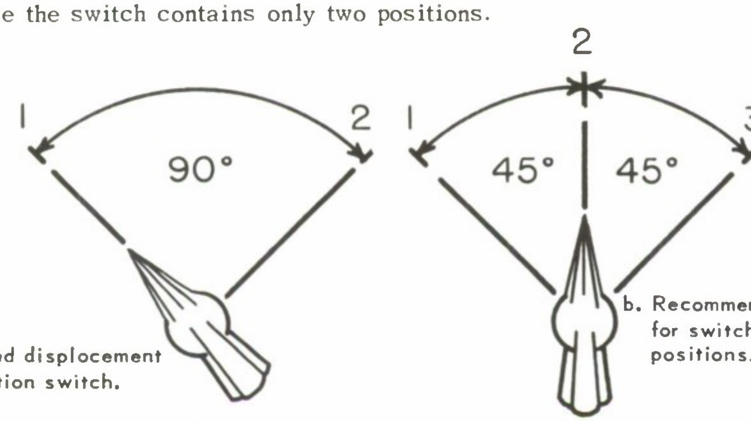
4. Make selector switches from 1 to 3 inches in length and no more than 1 inch wide.

5. Selector switches should not protrude from the panel surface less than ½ inch nor more than 3 inches.

SEPARATION BETWEEN POSITIONS

6. Switch positions should be no closer than 15 degrees apart. Minimum separation should be increased to 30 degrees where non-visual positioning may be required.

7. Maximum separation between positions for best operational performance is 45 degrees. This may be increased to 90 degrees where there is a special requirement for larger separation or where the switch contains only two positions.



a. Recommended displacement for two position switch.

b. Recommended displacement for switch with 3 or more positions.

Figure 12. Selector Switch Displacement.

8. Avoid having any two positions 180 degrees from each other. This situation, which may lead to setting errors and in reading the wrong end of the moving pointer, can be prevented by using less than the optimum (45 degrees) separation, as shown in Figure 13a.

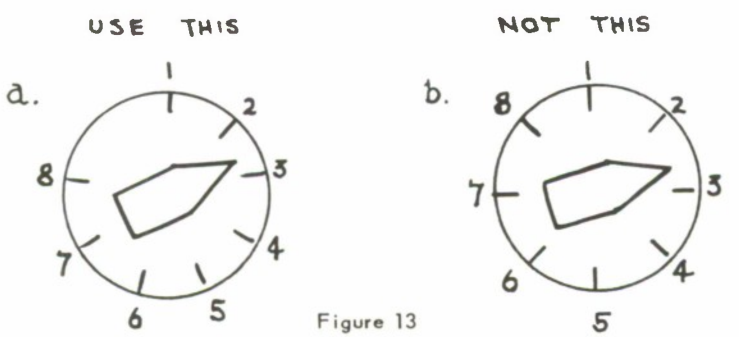


Figure 13

CONTROL FORCES

9. Design selector switches so that detent stops offer enough resistance to movement so that setting can be made by touch alone.

10. Control loading should be sufficient to offset the resting weight of the operator's hand, so that removing the hand will not inadvertently move the switch.

11. Force required to move selector switch from one position to another should be at least twelve ounces and should not exceed 48 ounces.

In general specify 32 ounces resistance for rotary selector switches as an optimum.

OTHER CONSIDERATIONS

12. Do not incorporate more than 24 positions in one rotary control.

13. Provide stops at the beginning and end of the range of control positions.

14. Position the pointer knob close to the scale to minimize parallax.

SECTION C. CRANKS

1. SELECTION OF CRANKS.

a. Select cranks for tasks involving at least two rotations of a control.

b. Specify cranks when turning speeds are above 100 rpm.

c. For operations involving rapid turning and accurate settings use a combined handwheel and crank, the crank to permit rapid transversing and the handwheel, gripped by the rim, to allow for accurate settings.

SIZE, SHAPE, AND LOCATION

2. DEPENDING ON LOAD AND TURNING SPEEDS, CRANK RADIUS MAY BE AS HIGH AS 20 INCHES.

a. For light loads and high speeds provide radius of 3 to 5 inches.

b. With heavy loads and high speeds radius of crank should be 5 to 9 inches.

c. For heavy loads and slow speeds radius may range from 9 to 20 inches.

3. CHARACTERISTICS OF CRANK HANDLE GRIPS.

a. Shape should allow large contact with the surface of the hand.

b. The handle should turn freely around its shaft.

c. Handle should be approximately 1½ inches long and ½ inch in diameter for fast wrist and finger movement; 3¾ inches long and 1 inch in diameter for operations requiring arm movement of heavy loads.

4. LOCATION OF CRANK DEPENDS ON CRANK SPEED, LOAD, AND OPERATOR'S POSITION.

a. Place cranks for the standing operator 36 to 48 inches above the floor.

b. Locate cranks so that their axis of rotation is in the vertical plane.

c. For light loads, with high rpm, locate cranks so that their axes of rotation are perpendicular to the frontal plane of operator's body.

Mount cranks on either side of the frontal work area in preference to mounting them in the center.

d. For heavy loads, use large side position cranks, with their axes of rotation parallel to the frontal plane of the operator's body.

e. For two cranks rotating simultaneously, place the cranks so their axes are perpendicular to the frontal body plane of the operator

OR

f. so that the right crank axis is parallel to the frontal body plane and the left crank axis is perpendicular to the frontal body plane.

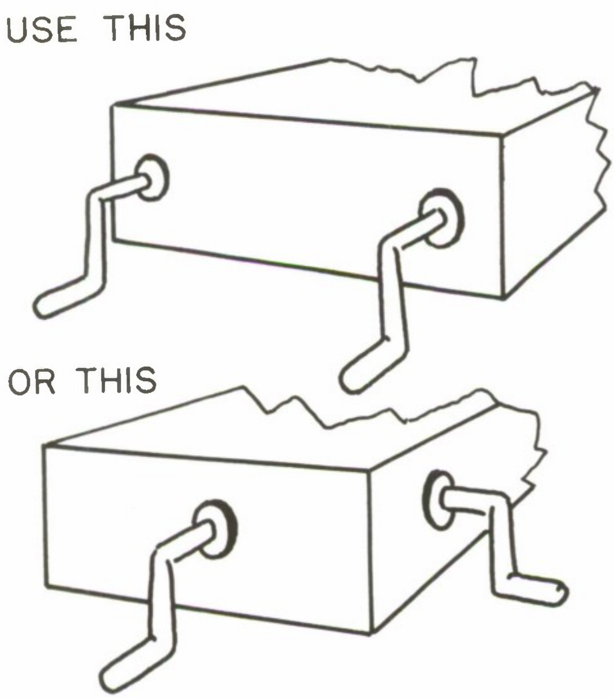


Figure 14

CONTROL FORCES AND SPEEDS

5. Small (less than 3½ inch radius), high speed cranks should have between 2 and 5 pounds load.

6. Large (up to 8 inch radius), high speed cranks should offer not less than 5 nor more than 10 pounds resistance.

7. Where a large crank is used for making precise settings control force should be between 2½ and 8 pounds.

8. To increase operator control when crank is to be rotated slowly, weight crank to increase inertia.

9. When cranks are used to keep a pointer on a moving target, use a high speed crank (up to 200 rpm) to make the movement more accurate and controlled.

10. If the range of crank operating speed is greater than 2 to 1, i.e., the fastest speed is more than twice the slowest speed, allow the operator a choice of two gear ratios.

   a. Provide each crank with three possible positions:

      (1) "IN" position for rapid slewing in either direction.

      (2) "OUT" position for fine adjustment.

      (3) A middle or neutral position to keep inadvertent movement from affecting the control. Crank should be spring loaded to return to the neutral position when pressure is released.

SECTION D. TOGGLE SWITCHES

1. Specify toggle switches when:

   a. Control functions require no more than three, preferably one or two discrete positions.

   b. Space limitations are severe.

   c. Fast and accurate operation is a requirement.

   d. Switches are to be used in groups and position checking is necessary.

   e. "Blind" setting or checking of position may be required.

2. Do not specify toggle switches when:

   a. The switch must be coded.

   b. More than three positions are required.

   c. Accidental activation cannot be tolerated.

3. Toggle switches should be mounted vertically wherever possible.

   a. Switch should move upward for ON, START, or INCREASE.

   b. Downward switch movement for OFF, STOP, DECREASE.

c. If toggle switches must be mounted horizontally, a motion forward or to the right should correspond to ON, START, and INCREASE, while a motion rearward or to the left should correspond to OFF, STOP, and DECREASE.

4. Make toggle switch lever arm from ½ inch to 2 inches in length and control tip size 1/8 inch to ½ inch in diameter.

5. Displacement of switch should be sufficient for visual and tactual discrimination.

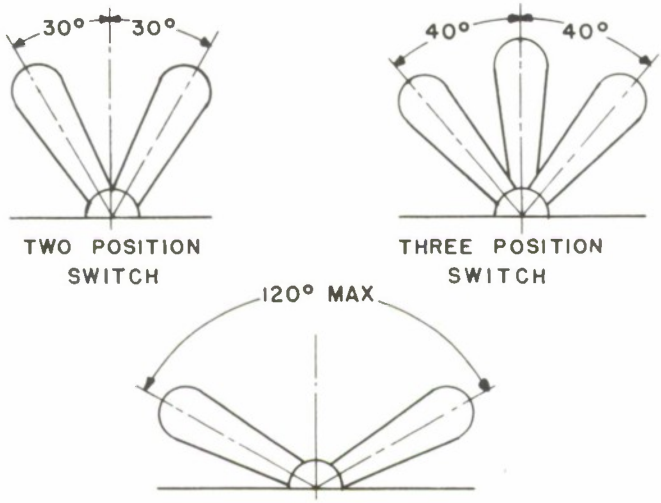


Figure 15

a. Displacement from center should be at least 30 degrees.

b. There should be a minimum of 40 degrees displacement between adjacent positions.

c. Do not provide more than 120 degrees total displacement.

6. When one panel contains a number of toggle switches, it is desirable that they all be OFF at the center position to facilitate checking of switch position.

7. Maximum force required to activate switch should be between 8 and 16 ounces.

8. When toggle switches are used as momentary contact switches, place them in such a position and operate them so that inadvertent activation is minimized. For example, place a switch of this kind near the bottom of a panel with the direction of movement upward.

Design spring tension in a spring loaded switch so that it is sufficient to return the switch to its normal position, but so that it does not require undue force to hold the switch in the active position.

SECTION E. LEVERS

1. WHEN TO USE LEVERS.

a. Where relatively large mechanical forces and/or displacements are involved.

b. Where multi-dimensional movement of the control is required.

SIZE AND SHAPE

2. Length of levers will be determined for each specific situation, including the required mechanical advantage.

   Length should permit comfortable and efficient actuation of the lever by all operators who are likely to use it.

3. Spherical lever handles should have:

   a minimum diameter of ½ inch for finger grasping.

   a minimum diameter of 1½ inches for hand grasping.

   a maximum diameter of 3 inches.

LOCATION AND CONTROL MOVEMENT

4. On levers perpendicular to the floor attempt to locate knob handles or grips between waist and shoulder of the operator.

   Hand grips on levers parallel to the floor should be placed approximately 28 inches above the floor for greatest lift by the standing operator.

5. Levers should utilize pushing movement for greatest accuracy.

6. For fastest operation of a lever mounted in front of the operator have the lever move in a fore-aft direction.

   When a lever is mounted in front of the operator and must move in a lateral direction, more force can be applied moving toward the left with the right hand than by moving toward the right with the right hand. Do not design lever to move laterally more than 38 inches, nor fore-aft more than 14 inches.

7. Levers should require a reach of no more than 38 inches for operation.

   When grouped levers in front of the operator pivot about a common axis or relatively close axes, they should move in fore-aft direction to avoid accidental activation of adjacent levers.

8. For maximum push, place the lever 29 inches from the seated operator's backrest.

9. Maximum push or pull for the seated operator is obtained with elbow at 135 degrees, hand grip at about elbow height, and lever moving in a vertical plane passing through the shoulder joint.

CONTROL FORCES

10. The force required to actuate a lever grasped by the hand should be at least 2 pounds.

    a. Increasing the friction of a lever tends to increase accuracy.

b. The addition of viscous damping or mass to a lever will help to maintain a more even rate of movement.

11. When a lever control is positioned close to the operator's body and is intended to be grasped by the hand, the maximum force required for push-pull movement with one hand should not exceed 30 pounds.

a. A force as great as 50 pounds is permissible with the control farther away from the body.

b. When both hands are used and the control is positioned close to the operator's body, twice as much force can be applied.

12. When a lever control is to be moved laterally, maximum control force for one-hand operation is 20 pounds and 30 pounds for two-hand operation.

13. Levers should be designed so that a torque change occurs between the initial and the terminal movement positions.

14. Detent pressure should be provided on discrete position levers.

SECTION F. PUSH BUTTONS

1. SPECIFY PUSH-BUTTONS UNDER THE FOLLOWING CONDITIONS

a. Space is at a premium.

b. There is need for a momentary contact control.

c. Necessity exists for activating a locking circuit in a high frequency of use situation.

d. Only one or two positions are needed.

e. Coding by color, size, or shape is a requirement.

f. Grouping is required.

g. Rapid switching between one of two positions is necessary.

h. Tester being designed is a hand-held unit. In this case specify push-buttons in preference to trigger type controls.

SIZE AND SHAPE

2. For thumb or heel of the hand operation, make the minimum diameter ¾ inch.

3. When push buttons are used for momentary contact switches make them at least 3/8 inch diameter.

4. Push button surface should be flat or concave to fit the finger.

a. The surface should provide a high degree of frictional resistance to prevent slipping.

b. It should be large enough so that it may be repeatedly pushed without discomfort.

5. When operator will have many push buttons to activate, and other tasks demanding his attention, consider using push buttons with raised (or lowered) forms to reduce possibility of error.

CONTROL FORCES AND DISPLACEMENT

6. Push buttons should have a minimum displacement of 1/8 inch and a maximum displacement of 1½ inches.

7. For fingertip operation resistance should be between 10-40 ounces.

8. Spring load push buttons for momentary contact switches.

9. Provide an audible click or detent to indicate that the control has been activated.

MOUNTING OF PUSH BUTTONS

10. In mounting push buttons provide safeguards against accidental activation.

    a. Use channel or cover guard.

    b. Flush mount push buttons.

    c. Recess push buttons below the plane of the unit.

11. For push buttons up to ½ inch diameter allow 1 to 1½ inches between centers.

12. For push buttons over ½ inch diameter allow at least 1 inch between edges of adjacent buttons.

13. Arrange push buttons in a horizontal array in preference to a vertical array.

CHAPTER IV. DISPLAYS

The function of a display is to provide the operator with information on which he can act. The information is usually presented by means of dials and scales, counters, scopes warning lights and buzzers, and printed material. On the basis of this information the operator makes decisions, manipulates controls, communicates with others, and handles emergency procedures.

SECTION A. SELECTING THE APPROPRIATE DISPLAY

The ultimate goal in selecting displays is to choose those that provide the operator with the exact amount of information required to carry out the functions of the system, but which present him no more information than he will have to use. Giving too little information can make the task of operation difficult, particularly in emergency situations. Too much information will make his task confusing.

1. CONSIDER THE FOLLOWING GENERAL PRINCIPLES WHEN SELECTING DISPLAYS.

a. The design of any machine requires consideration of the part which the operator is to play. It helps to orient design plans around the man-machine combination as a system to accomplish a given task. The man and the machine can be treated as physically separate but functionally interrelated units within this larger system.

b. The function which the man-machine system is to perform dictates the accuracy and speed requirements of the system.

c. Knowledge about operator capabilities dictates which type of display should be used, and also the accuracy and speed requirements of the display.

2. SELECT DIALS, SCALES, GAGES, OR METERS FOR CONDITIONS DESCRIBED BELOW.

a. To indicate direction of movement of the vehicle or orientation in space.

b. To distinguish increasing or decreasing trend of the values measured by the instrument.

c. When only an approximate reading is important.

d. For check reading rather than continuous monitoring.

e. For either quantitative or qualitative information.

3. DIRECT READING COUNTERS SHOULD BE USED.

a. For rapid and accurate reading of stationary or slowly changing quantitative information.

b. As an indication of revolutions in multirevolution indicators.

c. When economy of panel space is important.

4. SCOPES (CATHODE RAY TUBES)

a. Use scopes primarily for continuous monitoring activity.

b. Use scopes to monitor direction of movement of another vehicle as in radar.

c. Use scopes to monitor or check read frequency or amplitude waves such as sampling the output of a radar transmitter.

5. LIGHTS

a. Use lights for qualitative go/no-go indicators:

(1) On-off indicators

(2) Malfunction indicator

(3) Emergency warning lights (use flashing signal)

(4) Indication of inoperative equipment

(5) Caution indicator

(6) Indicators for operativeness of separate components

b. Use legend lights (words or numbers which are lighted from behind) for critical information when there is sufficient space on the panel.

c. Select lights when an immediate reaction of the operator is important.

d. Lights should be specified for notifying operator of the end of an operating cycle or approach of the end of a cycle.

e. Use lights as warm-up indicators for test equipment.

6. SELECT AUDITORY DISPLAYS (BUZZERS AND BELLS) FOR THE FOLLOWING SITUATIONS.

a. To notify operator of the end or approaching end of an operating cycle.

b. As an emergency or warning device.

c. As a malfunction indicator.

d. In conjunction with, or as alternative to lights.

(1) When environmental lighting conditions are such that lights might not be easily detected.

(2) When the operator will be occupied monitoring lights, dials, counters, and scopes.

(3) When multiple signals (warning, emergency, malfunction) are needed.

(4) When extreme redundancy is required.

SECTION B.

SCALES, DIAL FACES, AND POINTERS

1. GENERAL CONSIDERATIONS IN THE DESIGN OF SCALES

a. In most cases a circular scale is preferable to either a horizontal or vertical scale.

b. Of the two types of straight scales, the horizontal is generally recommended over the vertical.

c. When a number of instruments must be check read, the circular scale with moving pointer should be used.

d. When designing an instrument with fixed pointer and moving scale, the unused portion of the scale should usually be covered.

When such an instrument is to be used in tracking tasks, the full scale should be exposed.

e. When using several scales on one dial, use some device by which the scales may be easily identified.

(1) Use the same numerical progression for all indicators.

(2) Use pointers of different colors with scales to match.

2. ARRANGE NUMBERS ON SCALES SO THAT THEY ARE EASILY READ AND SO THAT NECESSARY OPERATIONS ARE FACILITATED.

a. Locate numbers so that they are not obscured by either the bezel or the pointer.

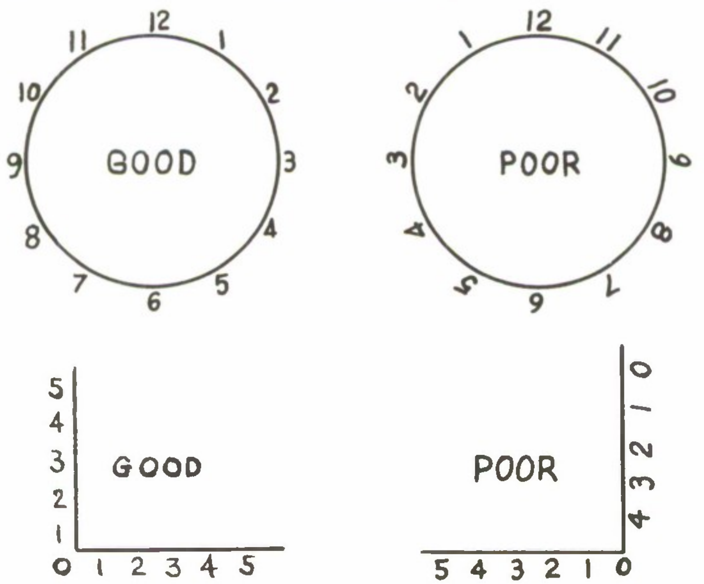


Figure 16

b. Design circular scales so that numbers increase in clockwise direction.

c. Design straight or drum type scales so that numbers increase from left to right or bottom to top.

d. On stationary scales orient all numbers vertically. Numbers always should be in the upright vertical position.

e. On moving scales orient all numbers to be upright at reading position.

f. On indicators that use moving scales and fixed pointers, the numbers should progress in magnitude clockwise around the dial face. Movement of the dial face should be counterclockwise to increase magnitude of reading.

g. All major scale divisions should be numbered.

h. Numbers and letters should be colored black and dial face should be white.

i. Height to width ratio of numerals should be 5:3.

3. SPECIFY NUMBER PROGRESSION ON SCALES TO BE CONSISTENT WITH NORMAL HABIT PATTERNS.

a. Optimum scale design is one with a major numbered graduation mark at each 10, and minor unnumbered division marks at each unit.

Numbering small subdivisions tends to decrease the accuracy to which a scale can be read.

b. Scale design should be such that an adequate reading is obtained by reading to the nearest whole number.

c. When number scales require interpolation, the intervals should progress by 10's or by 20's.

GOOD

1	2	3	4	5
5	10	15	20	25
10	20	30	40	50

POOR

4	8	12	16	20
2.5	5	7.5	10	12.5
5	22	75	87	100

Figure 17

d. Use graduation interval values of 1, 2, or 5 or decimal multiples. (See Fig. 17)

e. For feet and inches, use interval values of 1, 3, or 6 inches.

f. For pounds and ounces, use 1, 2, 4, or 8 ounces.

g. For some scales, such as clocks or compasses, the following scale progressions are best:

3	6	9	12
30	60	90	120
1	10	100	1000

4. ALL SCALES ON THE SAME EQUIPMENT SHOULD HAVE SIMILAR NUMBER ARRANGEMENT AND PROGRESSION.

a. Increasing values on all dials should progress in the same direction.

b. Make scale breakdown and numbering similar on all adjacent dials.

5. SIZE, HEIGHT, AND NUMBER OF SCALE MARKERS

a. Line markers should be the same width as the pointer.

Optimum width for both is one-tenth of a division width.

b. Provide sufficient markers so that interpolation on a scale need be no more accurate than one-fourth the space between two marks.

c. Mark height to mark separation ratio should be from 1:1 to 2:1. This ratio should never go as high as 5:1.

(1) Do not make height ratio of major to intermediate marks more than 1½ to 1.

(2) Make height ratio of intermediate to minor marks at least 1½ to 1.

6. SELECT GRADUATION INTERVAL VALUE (DISTANCE BETWEEN GRADUATION MARKS) APPROXIMATELY EQUAL TO DEGREE OF ACCURACY REQUIRED IN READING THE INDICATOR.

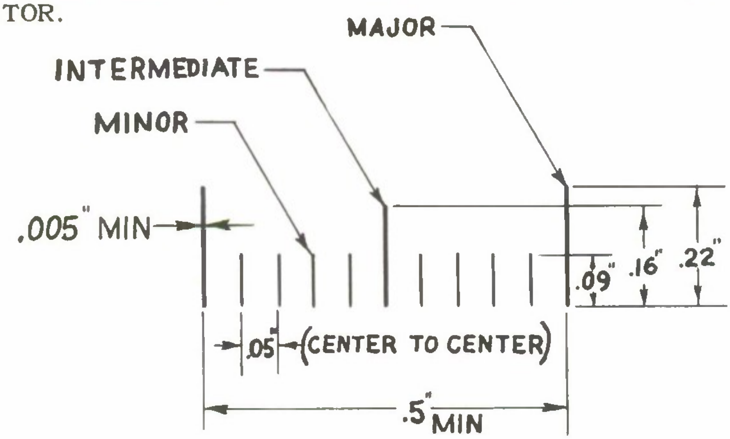


Figure 18. Graduation Intervals.

a. Scale divisions should not exceed the inherent accuracy of the instrument or the accuracy with which the instrument must be read.

b. Fig. 18 gives recommended minimum dimensions and spacing for graduation intervals.

c. The smallest scale markers may be spaced as close together as .05 inches, although the distance should not be less than stroke width.

d. A minimum of 0.5 inches is recommended for the distance between major graduation marks.

e. The number of graduation marks between numbered intervals should not exceed nine.

f. Select intermediate graduation marks so that the number of minor graduation markings between them does not exceed 4 or 5.

7. SCALE READING ACCURACY DEPENDS ON LINEAR SEPARATION OF GRADUATION MARKS.

a. To reduce the *size* of errors made on a scale, use finer scaling.

b. To reduce errors in interpolation (in terms of proportion of the intervals in which errors are made), increase the distance between markers. The optimum distance is ¼ ½ inch.

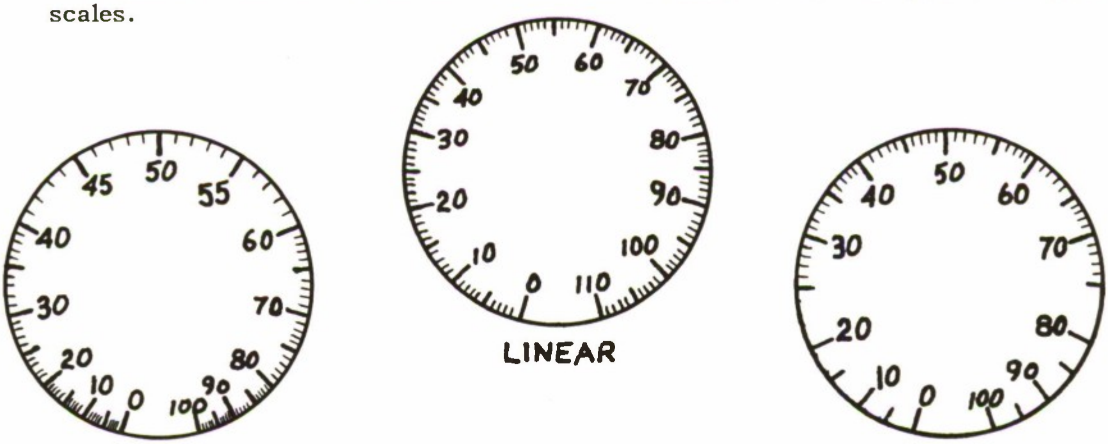
> Increasing scale intervals up to 1.5 inches will reduce time and errors in interpolation.

c. In scales graduated by tens the accuracy of reading to tenths of divisions increases as the distance between graduation marks increases to about 0.75 inches.

d. For greatest accuracy in reading scales to units, the distance allocated to each scale unit should be between 0.05 and 0.1 inch.

8. AVOID THE USE OF SCALES WITH IRREGULAR DISTANCES BETWEEN INTERVALS.

a. Figure 19 illustrates the difference between a linear scale and two types of irregular scales.



SIGMOID LINEAR EXPANDED

Figure 19. Linear and Irregular Scales.

b. Do not precede scale intervals which require maximum reading accuracy and speed in interpolation by scales of shorter interval length.

c. For expanded scales, graduation by units or twos is better than graduation by fives. Graduation by fives is, in turn, superior to graduation by tens.

9. STAIRCASE SCALES MAY BE USED TO AVOID CONFUSION AND TO AID IN INTERPOLATION.

The staircase scale (illustrated in Figure 20) is one in which the unmarked scale graduations increase in length from the lower numbers to the higher.

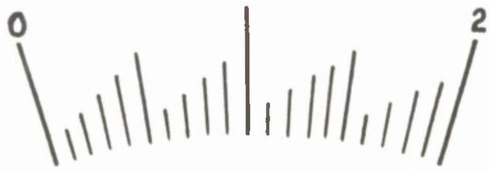


Figure 20. Staircase Scale.

10. CRITICAL REGIONS OF SCALES.

a. Critical regions of a circular scale should be assigned to the 9, 12, 3, or 6 o'clock position.

In designing scales to be calibrated positively and negatively from zero, locate the zero calibration in the 9 or 12 o'clock position.

b. On a semicircular scale place critical readings in the center of the scale.

c. On a linear scale avoid placing critical scale markings on or near either end of the scale.

d. On a vertical scale avoid placing critical scale markings at the top of the scale.

e. Dials which range over low scale values and are numbered by tens should be so oriented that the scale region over which the most frequent and/or critical quantitative readings are made appears in the left half.

f. When designing an indicator which is to be used extensively for check readings, indicate the desired reading or range on the scale. When a group of dials is to be used extensively for check reading, orient the dials so that all pointers are in the same relative position at the correct reading.

g. For circular scales there should be a scale break and the scale zero should be near the bottom.

When using a moving pointer and a fixed scale, provide an obvious scale break between the two ends of the scale of not less than 1½ divisions (except on multi-revolution instruments).

DIALS AND DIAL FACES

11. No one type of dial is best under all conditions. The designer must consider the proposed use of the dial, the limitations imposed by conditions such as lack of panel space, and the relationships of the various dials that constitute the particular display.

12. A fixed face dial is usually preferable to a fixed pointer dial.

13. Use dials with fixed pointers and moving scales when a large range of values will be included, panel space must be conserved, and only quantitative readings are required.

Only a portion of the scales should be exposed on dials of this type, but two numbers should be visible at all times to provide a reference for reading direction.

14. If vertical or horizontal direction is being measured, the meaningfulness of the information is increased by use of the vertical dial for vertical movement or horizontal dial for horizontal movement.

15. Unless there are overriding reasons for making them larger or smaller, circular dials should have diameters of from 1 to 4 inches.

Investigation has shown that when a panel contains many dials, 1¾ inch diameter dials are check-read more rapidly and accurately than dials which are considerably larger or smaller.

16. DESIGN DIAL FACES AS SIMPLY AS POSSIBLE.

a. Delete from dial faces all useless material, such as company trade names, model and serial numbers.

b. Each dial should be restricted to one quantitative scale and not more than two qualitative or check scales.

c. Place numerals on the side of the graduation marks away from the pointer to avoid having the numeral covered by the pointer.

If space is at a premium, numerals may be placed inside the marks to avoid constriction of scale.

d. The dial illustrated in Figure 21 is undesirable because:

(1) More than two quantitative scales are presented.

(2) Each scale requires a zero reset for a new reading because the "zero" of the three scales are not aligned.

(3) One of these scales requires a reverse reading.

(4) Pointer covers scale markings and numbers.

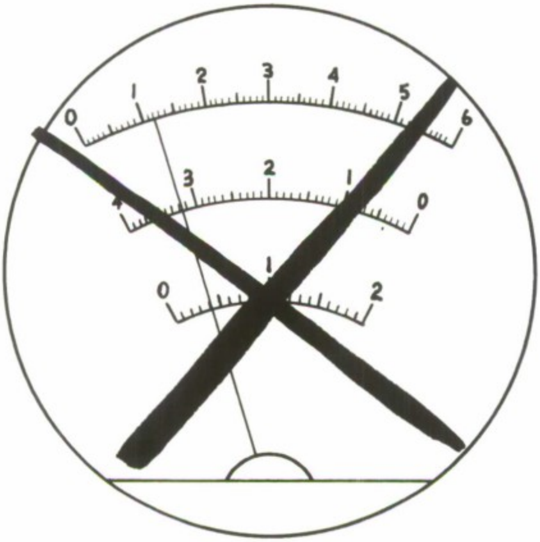


Figure 21

17. SPECIAL CONSIDERATIONS

a. Dial windows should be made of a substance which is less brittle than ordinary glass and which is resistant to scoring.

b. On transilluminated dials use a fluorescent or clear plastic disc with an embossed pointer.

c. When using a bank of dials with the pointers all pointing in one direction, use the 9 or 12 o'clock position.

d. When designing groups of dials requiring check reading, consider providing an illuminant on the dial which will change color as the dial deviates.

POINTERS

18. SIZE AND SHAPE OF DIAL POINTERS.

a. Pointer should be long enough to extend to the smallest graduation on all scales from which readings are to be taken, but should not cover the graduation mark.

> The pointer tip should not overlap dial numbers – a tip partially obscuring a 5 might cause the operator to read the 5 as a 6.

b. The pointer tip should be the same width as the narrowest scale markers and should be visible in both daylight and artificial lighting.

c. Full visibility pointers are superior to pointers of which only a short length of the tip is visible.

(1) When check or qualitative readings are necessary, the full visibility type pointer should be used.

(2) When only quantitative readings will be made, a partially covered pointer may be used.

d. Design pointers so there are no flourishes on arrow tips.

If pointer is to be used for reciprocal readings, the two ends of the pointer should be easily identified.

19. DESIGN AND MOUNT POINTERS SO AS TO MINIMIZE PARALLAX.

a. Mount pointer so that the tip is as close to the face of the dial as possible.

b. Include an anti-parallax mirror and knife-edge pointer with the knife edge about equal to the width of the division lines, and preferably not more than one-tenth of the distance between two successive scale division marks.

c. Paint the pointer the same color as numbers and scale markers.

20. LOCATION AND NUMBER OF POINTERS.

a. Pointers should be located to the right of vertical scales, and at the bottom of horizontal scales.

b. There should be no more than two tips on a single pointer shaft.

c. When the design of an instrument seems to call for multiple pointers, analyze the situation to insure that the use of multiple pointers will not introduce sources of human error.

d. As an alternative to multiple pointers consider using subdials or counters to augment the primary pointer.

21. MOVEMENT AND ORIENTATION OF POINTERS.

a. Numerical reading should increase by movement of a pointer up, to the right, or clockwise.

b. Where plus and minus values around a zero value are displayed, plus values should increase with movement of pointer up or to the right, and minus values should increase with movement down or to the left.

c. When designing an instrument which will be mounted in an array with other instruments, consider the total arrangement in arriving at pointer orientation.

(1) If instruments will be separated vertically, align pointer to read in-tolerance at the 12 o'clock position.

(2) For horizontally separated instruments or where there will be several rows separated both horizontally and vertically, align pointers at the 9 o'clock position.

SECTION C. COUNTERS

1. Use direct reading counters in lieu of dials when only a quantitative reading is necessary and the scale length would be such as to make a dial too complex.

   a. A counter may be used in conjunction with a single pointer instrument to indicate the number of revolutions of the pointer.

   b. On radar screen displays, a counter of the window type for range and/or bearing is more accurate than having operators read this information directly from scopes.

2. Avoid the use of counters for the following applications:

   a. A setting must be put into an indicator rapidly.

   b. The data change rapidly (more than 2 per second).

   c. A qualitative reading (change in direction or magnitude) is required.

   d. Several instruments must be monitored simultaneously, or for check reading.

3. Mount counters as close to the panel surface as possible to provide maximum viewing angle and minimize parallax and shadow.

   a. Avoid large horizontal spacing between number drums on counters.

   b. Counters should read horizontally from left to right rather than vertically.

   c. When visible area of counter drum around each number is small, make counter frame the same color as drum.

4. Numbers on counters should have a height to width ratio of one to one.

5. Numerical reading of counter should increase with upward drum rotation. This is especially important when a manual control is used to set numerical values into the counter. All digits should "snap" in, not "glide" in. Numbers should not follow each other faster than about two per second.

   "Glide" action may be preferred in those instances where range of readings is low and numbers change very slowly, provided that window is large enough for operator to see both numbers during transition.

6. Do not show useless digits when presenting information on a counter.

   a. When numbers are large and the last digits have little or no value, they should be replaced with stationary zeros.

   b. When numbers are small and zeros might ordinarily appear in the drums at extreme left, these drums should be blanked out completely during the time when no numerical value is to appear.

7. When a counter is used to indicate sequencing, the equipment should be designed to reset automatically upon completion of the sequence.

8. To set-in numbers on manually-operated counters:

a. Use knobs in preference to thumb wheels.

b. Make control-display ratio such that one revolution of knob equals about 50 counts, i.e., right hand drum rotates 5 times.

c. Clockwise rotation of knob should result in increase of number on counter, and upward movement of drum.

SECTION D. SCOPES

1. When plotting is not required, a 5 to 7 inch scope diameter is adequate. Use larger sizes for accurate plotting.

2. The shape of the bezel or frame around a scope should be dictated by the type of presentation.

Use a round frame for a PPI presentation and a rectangular frame for an A-scan device.

3. Design scope to insure maximum viewing efficiency.

a. Surround scope by non-reflecting surfaces and edges.

b. When high ambient illumination can not be avoided, provide hoods or recess face of the scope.

c. Avoid direct light reflection wherever possible.

d. Use filters on flat-face tubes to reduce surface reflections.

4. Provide supports to increase accuracy of scope interpretation.

a. Scopes which must be read accurately should be equipped with a cursor or pantograph.

Electronic cursors are useful in eliminating parallax, increasing accuracy.

b. Use range rings on circular scopes to aid operator in estimating target range.

(1) Increasing the number of range rings will usually improve accuracy, but may degrade speed.

(2) Increase the scope size, if accuracy is critical.

(3) The range ring numbering system should progress in one's, two's or five's (or multiples thereof). For instance, a 250 mile range might have 25 range rings, each corresponding to 10 miles; or 5 range rings, each corresponding to 50 miles.

c. The minimum distance between range rings is ½ inch at the normal viewing distance of 18 inches. If more than four range rings are used, make half of them dotted and half solid.

d. If accuracy of bearing readings is important, provide a solid line every 30 degrees and dotted lines every 10 degrees.

e. When wave forms must be matched, provide standards which are visible to the operator while he is doing the matching.

SECTION E. WARNING DISPLAYS

AUDITORY VERSUS VISUAL WARNING DISPLAYS

1. USE VISUAL INSTEAD OF AUDITORY DISPLAYS

a. For responses demanding quick selection from a large stock of information (information presented in a short space of time or simultaneously).

b. When responses demand rapid referability (maps, instructions, check sheets).

c. For responses demanding relational comparison. such as the level of liquid in two tubes.

d. Where responses demand fine, qualitative discrimination.

e. Where previous habit patterns would make operator expect visual presentation.

2. USE AUDITORY INSTEAD OF VISUAL DISPLAYS

a. Under conditions of reduced operator attention.

b. When environmental conditions, such as low illumination levels, handicap visual presentation.

c. If the visual sense channel is oversaturated.

d. Where timing is important, such as a "ready now" signal.

e. If the rate of information input is very low, but where it must be relatively continuous, such as monitoring a process continuously.

f. For an alarm, when a signal must be given at an unexpected time during a long continuous watch.

g. Where previous habit patterns would make operator expect an auditory presentation.

3. USE EITHER AUDITORY OR VISUAL DISPLAYS

a. For signals already anticipated by the operator.

b. For responses which are discrete, short, and follow a presentation quickly.

4. USE BOTH AUDITORY AND VISUAL DISPLAYS

a. Where environmental conditions handicap data presentation through either sense alone (low illumination or high noise levels).

b. For warnings of extreme emergency.

c. Where great redundancy is desirable.

AUDITORY WARNING DISPLAYS

5. DESIRABLE CHARACTERISTICS OF AUDITORY WARNING SYSTEM

a. It must be easily detectable.

b. The signal should hold operator's attention.

c. It must be distinctive – quickly and accurately identifiable.

d. It must be "infinitely" retainable as a function of time with regard to its meaning.

6. MAKE SIGNALS DISCERNIBLE WITHIN THE ENVIRONMENT IN WHICH THEY WILL BE PRESENTED.

a. Auditory signals should be different enough from background noises that they may be easily identified.

(1) Use undulating or warbling tones.

(2) Make the sound at least 20 decibels above threshhold.

(3) Use a tone of lower frequency than that of the local noise, but do not use frequency below 500 cps.

7. DO NOT USE SIGNALS WHICH GIVE THE OPERATOR DISCOMFORT OR WHICH EXCEED HIS CAPABILITY FOR RESPONDING.

a. Do not use continuous high-pitched tones as warning signals.

Do not use as signals, sounds above 2,000 cps.

b. Make the initial sound in a warning system as brief as possible while still maintaining the criteria of being detectable, attention-demanding, and category discriminating.

c. Make auditory signals as brief as possible to reduce the need for over-lapping or simultaneous monitoring of reception.

Require simultaneous monitoring of two or more auditory channels only when each channel contains information directed toward a single operation, and none of the information is contradictory.

d. Avoid the use of auditory signals which require interpretation while the operator is performing a repetitive task.

e. Separate spatially, auditory channels used by different operators.

VISUAL WARNING DISPLAYS

8. INDICATOR LIGHTS SHOULD BE PROVIDED TO GIVE OPERATOR INFORMATION ON STATUS OF EQUIPMENT.

a. To warn of extreme emergency conditions use a one inch diameter flashing red light.

b. For extreme cautionary conditions indicating impending danger, specify a one inch diameter steady amber light.

c. For master summation indications, system or subsystem, use a one inch diameter steady red or green light.

d. Indicate all other conditions by use of a ½ inch diameter steady light.

All one inch diameter lights should be approximately twice as bright as ½ inch diameter lights.

e. Light indicators should be used sparingly.

(1) Lights which are referred to infrequently and only under special circumstances, such as maintenance, should be concealed but easily accessible and visible when required.

(2) When there are many lights on a single panel, provide a master light which tells when any portion of the system is operating out of tolerance.

f. Indicator light should be provided on all testers to indicate that warm-up is completed.

g. Provide indicator signal lights to notify operator of end of cycle or approaching end of cycle.

h. Provide signal lights near danger points.

9. GENERAL CONSIDERATIONS

a. Signals which demand immediate attention for the correction of critical malfunctions should be designed so they occur only when the malfunction is present or in prospect of occurring in the immediate future.

b. Lights should be located on or near the control that must be manipulated.

If the control is not near the operator's normal line of sight, the light should be placed where it will be seen quickly even though it may not be near the control.

c. Whenever possible the warning device should tell the operator what corrective action is needed.

(1) This may be done by using legend lights.

(2) Legend light lettering should be visible and legible at all times.

(3) Lights should be clearly labeled, the labels adequately illuminated, and the wording of the labels clearly indicating what should be done.

d. Spacing between adjacent edges of light fixtures should be at least ¾ inch.

e. So that operator can rely on warning lights being operative, provide a press-to-test capability or design each warning indicator with two lamps in parallel so that if one burns out the other will still give an indication.

10. COLOR CODING OF LIGHTS

RED	Indicates something is wrong – a unit is inoperative or an emergency condition exists. Use red for conditions which require immediate action, or for indications of unsatisfactory or hazardous conditions.
AMBER or YELLOW	Condition not unsatisfactory in itself, but indicative of an impending unsatisfactory or hazardous condition. Conditions which require alertness and caution. Indicates caution, delay, check, or recheck is necessary.

GREEN	Indicates equipment operating or satisfactory condition. Instructs operator to proceed for all is satisfactory.
WHITE	Indicates neutral status without implications of "right" or "wrong". Used the same as GREEN in order to restrict GREEN lights to power indicator lamps. Do not use white under conditions requiring night vision.
BLUE	Action is in progress, or standby.

11. BRIGHTNESS OF LIGHTS

a. Make warning lights at least as bright as the brightest source on the panel.

b. Warning lights should be at least five times as bright as the surroundings.

To maintain this brightness contrast provide a brightness level control.

c. Lights should not be so bright as to interfere with control setting and meter reading necessary to the operations involved.

d. Provisions should be made to prevent reflected sunlight from making lights appear as illuminated when used outdoors.

Frost, or otherwise treat, all pilot and warning lights.

12. SPECIFY FLASHING LIGHTS FOR CONDITIONS REQUIRING IMMEDIATE ATTENTION.

a. Bright, flashing lights are better for warning than steady lights.

b. Flashing interval should be 3 to 5 per second.

c. "On" time should be approximately equal to, but not greater than, "off" time.

d. Duration "on" should be at least 0.1 second.

e. Make provision for light to burn steadily if flasher device fails.

SECTION F. CONTROL-DISPLAY RELATIONSHIPS

> This section is concerned with direction and rate of control movement as they relate to direction and rate of display movement. Recommendations for relating positions of controls and displays are contained in Chapter five.

1. DISPLAY-CONTROL MOVEMENT RELATIONSHIPS SHOULD BE COMPATIBLE WITH OPERATOR EXPECTATIONS.

a. Clockwise movement of a rotating control should make the associated display move clockwise.

If display is not of the rotating type, clockwise movement of control should move display right or up.

b. For lever type, horizontally mounted controls, forward movement should result in clockwise, right, or up movement of the associated display.

c. If lever type control is vertically mounted, upward movement of the control should result in upward, clockwise, or rightward movement of the associated display.

d. Moving a lever type control to the right should result in the associated display moving right, clockwise, or up.

e. When levers are used to control pointers, best performance is obtained when both lever and pointer travel through parallel arcs. Performance improves when the pointer and lever are both pivoted alike.

f. Movement of a control and movement of its associated display should lie in the same plane wherever possible.

g. For controlling joysticks or levers, it is more important that there be a direct control-display relationship in lateral movement (moving lever right moves display right) than that there be a direct relationship in fore-aft movement (moving lever forward moves display down).

h. Direction of movement relationship is most important where control and display are parallel in line of movement.

i. If necessary to design control so that its movement is not in expected direction, all related control movements should also be in reverse direction.

Where desirable control-display relationships cannot be adhered to, it is especially important to label controls indicating the direction of control movement required.

2. CONTROL MOVEMENTS SHOULD BE CONSISTENT IN THEIR EFFECT ON EQUIPMENT.

a. Control movement FORWARD, CLOCKWISE, RIGHT, UP, PRESS, or SQUEEZE should turn equipment or component ON or cause quantity to increase (for example, louder, brighter, faster, or greater).

b. In terms of equipment motion, control movement FORWARD, CLOCKWISE, RIGHT, UP, PRESS, or SQUEEZE should cause equipment or component to move forward, clockwise, to the right, or up.

3. RATIO OF CONTROL MOVEMENT TO DISPLAY MOVEMENT

a. When a wide range of display movement is required, small movement of the control should yield a large display movement.

b. When a fine adjustment is required, a large movement of the control should yield a small movement of the display.

c. When a wide range of display movement is required, but the end setting is precise, the ratio of control-display movement should be kept at a medium value.

(1) To facilitate this setting, provide both a coarse and a fine setting for the display.

(2) If a knob or wheel type control is used, add a crank to facilitate the coarse setting.

d. Avoid factors in design which cause the display indicator to continue moving after control movement has ceased.

e. A ratio of about 1 or 2 inches of pointer movement to one complete turn of a control knob is optimal in making settings on a linear scale (in terms of time taken to make the settings).

Knobs are superior to levers in making pointer settings.

f. Make the time lag between control movement and display activation as short as possible.

g. When movement of an indicator in two dimensions is controlled by a joystick and the relationship of movement is direct, make the ratio of cursor to joystick movement 1:2.5.

h. When a rotary control is used with a linear indicator, the indicator should move in the same direction as the edge of the knob nearest the indicator.

CHAPTER V. PANEL LAYOUT

The panel of a piece of test equipment is the point at which the man and the machine come together. It is essential that this link be properly designed. Controls that the operator manipulates to change the state of the equipment are located here; as are the displays which indicate to him what he should do, when he should do it, and whether what he has done is adequate.

The general principles contained in this chapter will help the designer to produce test equipment which is adapted to the needs of the average operator. Each tester, however, presents individual problems. Therefore, in addition to considering the recommendations in the following pages, the designer must analyze the operations to be performed on the particular piece of equipment he is designing. He must also examine the environmental conditions under which the equipment will be operated to determine whether clothing to be worn will demand certain changes in design, or whether night time operation, operation under conditions of low illuminations, or operation over extended periods of time will impose stresses on the operator which will have to be considered. The recommendations contained in this chapter cover many of the contingencies mentioned, but it is only by an analysis of the job to be performed that the designer can decide which recommendations are appropriate.

SECTION A. PLACEMENT OF CONTROLS, DISPLAYS, AND CABLE CONNECTIONS ON PANELS

1. PLACE FREQUENTLY USED OR CRITICAL CONTROLS AND DISPLAYS IN PREFERRED LOCATIONS.

a. Measured vertically the best position lies in a U-shaped area on either side of the center of the body, the bottom of the U being at about elbow level, and its width about double the distance across the shoulders, the uprights of the U extending approximately shoulder height.

Horizontally, the preferred location is determined by arm reach – the best position being within an arc of 16 inches from the body.

b. Figure 22 below illustrates the approach to the locating of controls, displays and connectors on the front panel of a portable tester. Ordinarily when designing this type of tester, the designer cannot assume a particular orientation of operator and tester, since the tester may sometimes be set on the floor and at other times placed on a stand or bench.

c. Frequently monitored displays should be grouped and mounted within the operator's normal line of vision.

(1) Locate in optimum position so that they are easily seen or readily operated those controls and indicators whose operations are critical under emergency conditions.

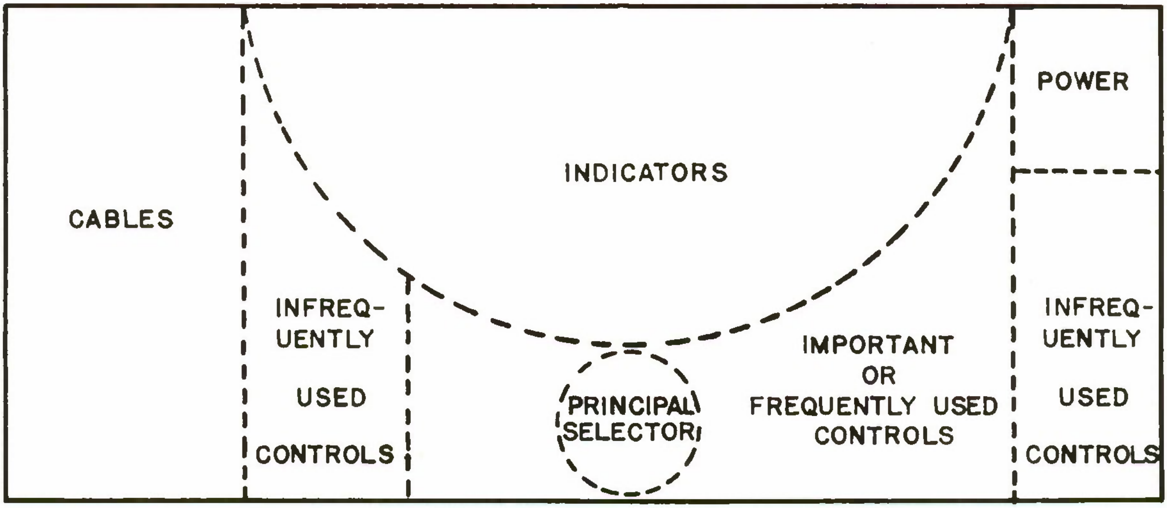


Figure 22

Suggested Arrangement for Front Panel of Portable Tester

(2) Controls and indicators which are employed for long uninterupted periods should be located in preferred positions.

(3) Infrequently used displays may be placed in the periphery of the visual field.

(4) Figure 23 is an example of the way in which displays might be placed in the central area of a tester panel.

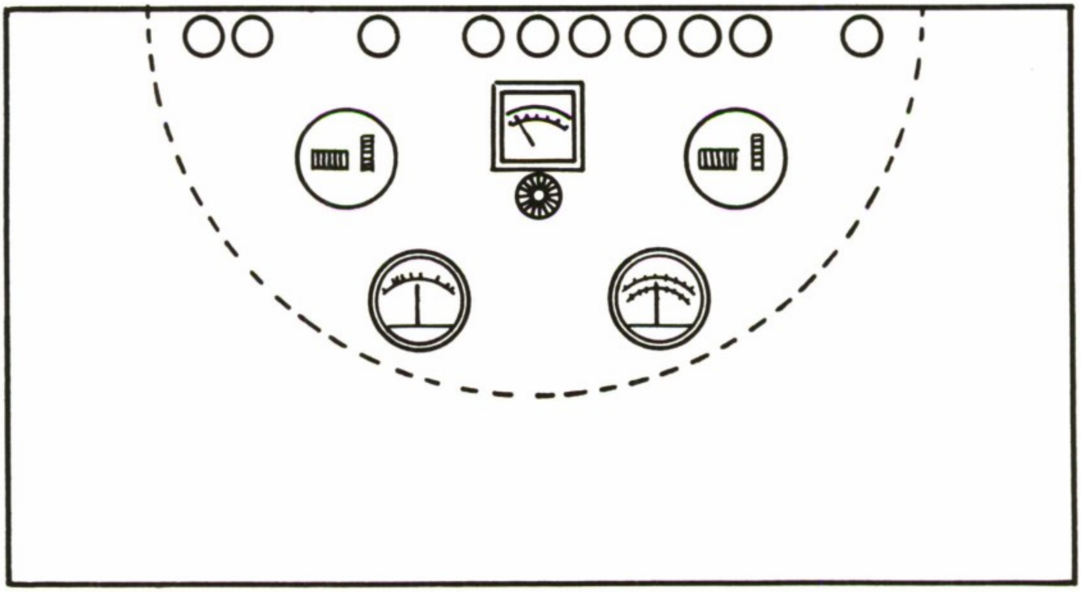


Figure 23

Arrangement of Displays in Central Area of Portable Tester Panel

d. Frequently operated controls should be placed between elbow and shoulder height, off center in line with the arm plane, and as close as possible to the normal working position.

(1) Place frequently used controls within an arc of 16 inches from normal working position; occasionally used controls within an arc of 20 inches; and infrequently used ones within an arc of 28 inches.

(2) Frequently used controls should be designed for right hand operation and placed within comfortable reach.

(3) Group frequently used controls, unless there are overriding reasons for separating them.

(4) If a frequently used control must be placed outside the central area of the panel, provide a warning light in the central area to indicate when the control should be activated.

(5) When controls are operated frequently or for long periods of time by the arms or feet, locate them to the left front or right front of the operator.

(6) Cover or place to one side, controls which are infrequently used, if there is a possibility that they may be inadvertently activated.

2. MAKE ALL CONTROLS AND DISPLAYS ACCESSIBLE AND READABLE

a. Controls and displays should be designed so that the operator can visually check their positions and/or readings accurately, regardless of the angle from which viewed.

b. All controls should be within the maximum reach of the operator when seated.

c. All controls should be located where they can be seen and operated without disassembling or removing any part of the installation.

(1) Controls which are only occasionally required may be mounted behind hinged doors or recessed in the panel to prevent inadvertent use.

(2) Seldom used adjustment controls should have shaft locks or have screw driver slots.

(3) Position controls so that servicing, adjustment, and replacement of equipment will not be hampered or made unduly difficult.

(4) When dials or scopes must be watched and controls manipulated sumultaneously, place controls within easy reach.

(5) All maintenance controls should be located on one side of a unit (a side which will be accessible in the normal installation).

(6) Unless there are overriding reasons against it, mount all controls on the outside of units.

(7) Place controls so as not to obstruct the operator's view of indicators.

d. Viewing distance to displays should not exceed 28 inches.

Viewing distance should never be less than 13 inches and preferably not less than 20 inches.

Place all displays to be used together at the same viewing distance.

e. The visual angles of details which must be read on displays should not subtend less than two minutes of arc under good illumination and brightness contrast. (Good illumination is at least 50 footlamberts at a minimum of 50 percent brightness contrast).

f. Warning lamps should be within 30 degrees of the normal line of vision and adjacent to the control with which the operation is to take action.

g. For use as signals avoid placing

words – more than 5 to 10 degrees from direct line of vision.

symbols – more than 5 to 30 degrees from direct line of vision.

color – more than 30 to 60 degrees from direct line of vision.

3. PLACEMENT AND GROUPING OF ASSOCIATED CONTROLS AND DISPLAYS

> The term "associated controls and displays" refers to those controls which are associated with particular displays, as well as controls or displays which are associated with other controls or displays because of similarity in function, sequence, system to which they pertain, or operations performed.

a. Displays with similar functions which are likely to be read together should be grouped.

(1) Grouping may be achieved by spatial location, or by color, size or shape coding. (See Section C for coding recommendations.)

(2) If spatial grouping is used, the group may be isolated by enclosing it with a white line or by using fields of different colors as backgrounds. (It should be noted that the more groups of this type that are used, the less effective they are.)

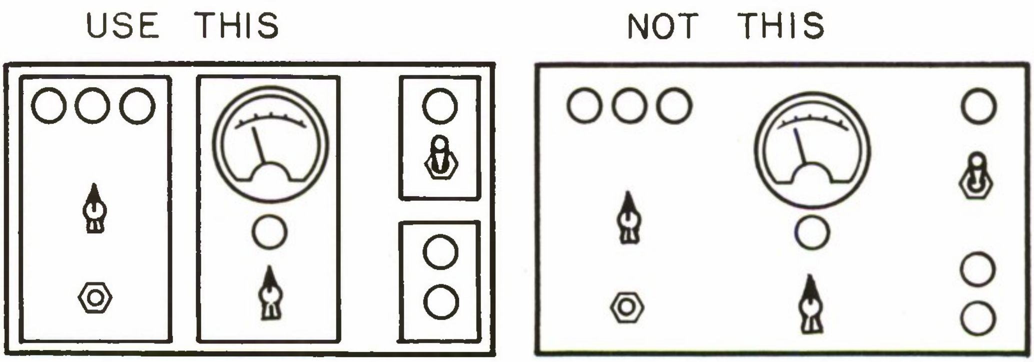


Figure 24

b. All controls and displays used in a given procedure should be located on the same panel.

When two or more controls must be activated simultaneously, or in rapid sequence, place them so they both can be reached from a fixed position.

c. Controls and displays should be grouped according to the system to which they pertain. On a complex panel, for instance, the controls for a particular computer should be placed close together.

d. Place controls close to the display they affect, but far enough away so that when control is activated, operator's hand will not obstruct his view of the display.

(1) Controls operated by the right hand should be located below or to the right of their associated displays.

(2) Controls operated by the left hand should be located below their associated displays. They may also be located to the left of the display provided that direction of motion relationships suggested in Chapter IV are not violated.

e. When a toggle switch is used with a counter, the frontal plane for mounting is preferred.

(1) Mount switch so that the counter is operated by throwing the switch to the right.

(2) A counter can be efficiently controlled by toggle switch when rotating at 10 units per second.

f. When a knob or lever control is mounted below a display, the 12 o'clock position on the display is significantly superior for critical settings to the three, six, and nine o'clock positions.

g. When concentric (ganged) knobs are associated with displays, the displays should be arranged in a row from left to right. The front (small) knob should control the left display, the middle knob the middle display, the back knob, the right display.

When the manipulation of one control requires the reading of several displays, place the control as near as possible to the related displays and beneath the middle display.

h. Mount controls on the same plane as the displays they control.

Displays and controls should move in the same plane of space.

i. Place controls so that there is an equitable distribution of work load between right and left hands. Right hand operation should be used for operations requiring the finest adjustments.

j. Place all controls of a similar type so that they turn on and off in the same direction.

k. Retain same relative grouping for major controls and displays in all similar models of equipment.

(1) The relative position of controls should not be changed from one piece of equipment to another piece of similar equipment. If it is absolutely necessary to change the position of controls it is essential that the shape of the handles on the controls being changed remain the same as they were originally.

(2) When controls and displays are located on separate panels and both panels are mounted at approximately the same angle relative to the operator, the controls on one panel should occupy positions corresponding to those of their associated displays on the other panel. The two panels should *never* face each other.

1. When there are a large number of displays on the same panel they should normally be arranged in either of the two following ways.

(1) Each display directly above its associated control.

(2) All displays in the upper portion and all controls in the lower portion of the panel. Each control then should occupy the same relative position as its associated display.

4. ALIGNMENT AND SEPARATION OF CONTROLS AND DISPLAYS ON A PANEL.

a. Align dials horizontally rather than vertically.

(1) If dials are vertically aligned mount them so that the "normal" position of the pointers is at 12 o'clock.

(2) If dials are horizontally aligned mount them so that the "normal" position of the pointers is at 9 o'clock.

(3) Whenever it is necessary to note that one indicator out of a series of dials is out of alignment, arrange the indicators so that all pointers except the one out of alignment would read, at the 3, 6, 9 or 12 o'clock position.

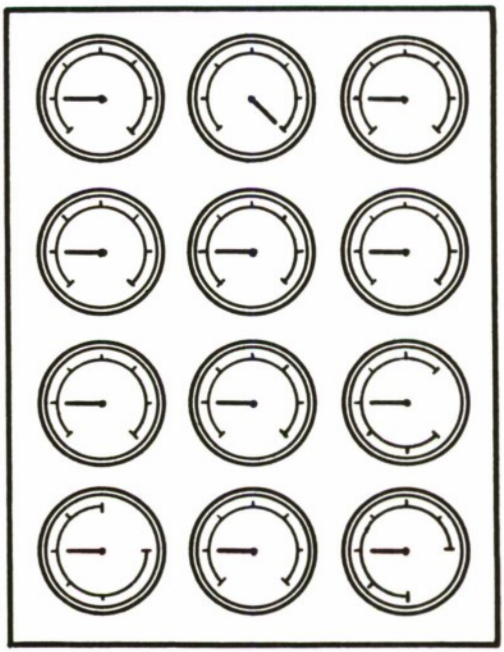


Figure 25. Check Reading Dials.

b. Dial separation (horizontally or vertically) should be no more than 4 inches.

c. Placement of one control should not hinder the operation of another, controls should be effectively placed for operational sequence, and routine controls should not be confused with rarely used ones.

(1) Place controls so that one control is not located behind another of similar height.

(2) Place controls which yield fore movement at the top of a vertical panel and controls which yield aft movement below them.

(3) Do not place more than two controls of the same kind and shape side by side except in the case where a crowded and complex control panel makes a whole series of similar controls difficult to locate.

d. Separate controls or displays which may be easily mistaken for one another.

(1) Discriminability can be increased between two similar controls by an increase in physical separation.

(2) Operating controls in front of the operator should be mounted 6 to 18 inches apart.

(3) Mount operating controls 12 to 16 inches apart if they are located at the operator's side.

(4) Where a single group of two multi-position selector switches and a toggle switch must be placed in a row, discriminability between the two selector switches can be increased if they are separated by the toggle switch.

5. ARRANGE CONTROLS AND DISPLAYS IN SEQUENCE OF THEIR USE.

a. Group controls which are always used in a fixed sequence or for a particular function, to facilitate their use and effect economy of operator motion.

(1) Place controls so their relative positions will coincide with the sequence in which they will be operated.

(2) Place controls so the direction of motion in which each will be operated leads directly to the control to be operated nest. (Natural sequence is from left to right.)

(3) When one limb must operate two or more controls in sequence, arrange the controls to allow for continuous limb movement (from left to right, through an arc, etc.)

(4) Design controls to avoid hunting and/or back tracking.

b. When controls are used sequentially by the same hand they should be arranged so that the operator moves his arm horizontally from one to the next. When they cannot be aligned horizontally they should be arranged in some systematic manner such as vertically from top to bottom.

c. Controls to be operated simultaneously should be placed close to each other.

Locate such controls so that the operator's hands will not have to cross each other, be interchanged, or obscure his view of an indicator he must use.

d. Controls and displays to be used or referred to in sequence should be grouped together, their sequence should be indicated by numbering, and their position should be emphasized by outlining or color coding.

e. Displays used in sequence should be grouped in such a way that they can be read from left to right or from top to bottom.

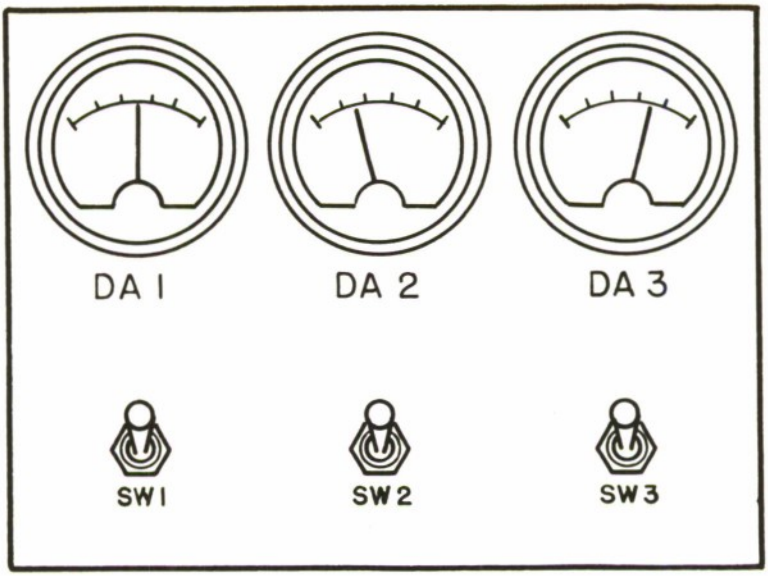


Figure 26. Arrangement and Numbering of Controls and Displays Used in Sequence.

f. If several control-indicator units are operated alternately or in sequence, the relative position of, and the motion relationship between indicators and controls, should be alike on all of the different units.

6. ANGLE OF PANEL

a. Mount displays perpendicular to the line of sight.

(1) Maximum deviation for displays other than scopes – ± 45 degrees.

(2) Maximum deviation for scopes – ± 30 degrees.

7. DESIGN PLACEMENT OF CONTROLS TO REDUCE POSSIBILITY OF INADVERTENT ACTIVATION, DAMAGE, OR PERSONNEL INJURY.

a. Controls should be accessible and out of dangerous areas.

b. Use of controls should not permit injury to other parts of the equipment.

c. Place frequently used controls so that other controls do not have to be avoided.

d. Place controls far enough apart so that the operator's hand, arm, or clothing cannot come in contact with a control other than the desired one.

e. Increase space between knob edges up to 1 inch to decrease errors in touching adjacent knobs inadvertently.

f. The best position for knobs least likely to be touched accidentally is directly to the left and above the operated knob.

g. Accidental touching is less frequent in a vertical array than in a horizontal array.

h. Place controls which are used in rapid sequence far enough apart to prevent accidental activation of control other than the desired one, but no further.

i. Keep controls away from high voltage points and hot tubes.

8. LOCATE CONTROLS SO THEY CAN BE OPERATED WITH THE LEAST EXPENDITURE OF ENERGY

a. All controls should be placed within a practical working distance.

b. Place each control in the area in which it can be most efficiently used.

c. For a linear arm movement where the arm is *not* supported, locate controls to place the action in the vertical plane.

d. Where space is a problem, manually operated controls may be located either medially or in line with the shoulder of the preferred hand, provided the movements to be made are of short duration.

e. Controls which demand maximum force from an operator should be placed in front of the operator and designed so that they can be operated by pulling.

> A straight pulling motion from a position in front of the body gives the greatest power. A long backhand sweep with the arm extended gives the second greatest power.

f. For maximum forces, place levers at shoulder height for standing operators and at elbow level for seated operators.

g. Place frequently used controls so that operators will not be forced to maintain awkward positions (reaching way up or holding the arm extended) for long periods of time.

> Infrequently used, but critical, controls should be located so they do not require excessive stretching.

h. Do not exceed reach of the average operator when laying out controls.

i. Distribute controls so that no one of the operator's limbs will be overloaded and each will be used most effectively.

(1) Assign to the hands controls which require high precision and/or speed of operation. Assign major load to right hand.

(2) Assign to the feet controls which require large application of force.

9. PLACEMENT OF CABLE CONNECTORS ON PANEL

a. Cable connections, receptacles, and plugs should be placed on the left side of the panel in a separate section.

b. When possible, angle this section back away from the plane of the panel, or else use right angle connectors.

c. Receptacles should be placed so that the larger or more bulky cables are at the bottom and the smaller ones nearer the top with the power receptacle and fuses at the very top of the stack.

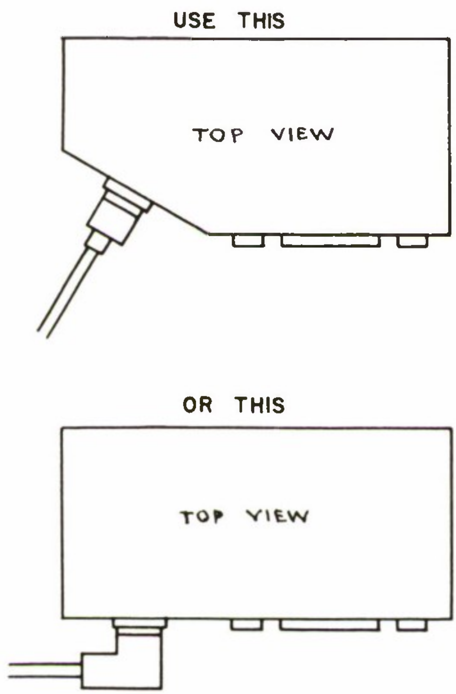


Figure 27.
Cable Connections.

SECTION B. PANEL LABELING

1. IDENTIFY ALL CONTROLS AND DISPLAYS BY CLEAR AND UNAMBIGUOUS LABELS.

a. Label instruments according to what is measured, *not* by the name of the instrument.

Use RPM not tachometer and VOLTAGE not voltmeter.

b. Controls should be labeled by function and direction of movement.

(1) Place high contrast arrow-type pointers at the extremity of the control movement to show direction of movement and place labels at the tips of the arrows.

(2) Place numbers on switch panels to designate the order in which the switches are to be activated.

(3) Label controls to indicate direction of movement of the display with which they are associated.

c. Make labels brief using only words which are familiar to the individual who will be operating the equipment.

(1) Use abbreviations *only* if they are familiar to the operator.

(2) Where two controls or displays are identical, use labels which are also identical.

2. PLACEMENT OF LABELS ON PANEL

a. Position labels on controls or immediately adjacent to them (above if possible).

Place labels so they are not masked when controls are manipulated.

b. Place labels so they do not crowd or obscure other useful information.

c. All labels should be in full view, not askew or upside down.

d. Labels should be read horizontally, not vertically.

e. On a circular display with a fixed scale, place label in the center of the dial face.

f. Do not place trademarks or manufacturer's labels on visible portion of control or indicator.

g. Labels should be engraved on separate plates and attached to the panel individually when feasible.

h. Labels which number or letter controls or displays should be assigned from left to right on a panel.

i. Labels should be consistently in the same place in relation to the instrument. Do not place some labels under and others over the part they identify as in Figure 28.

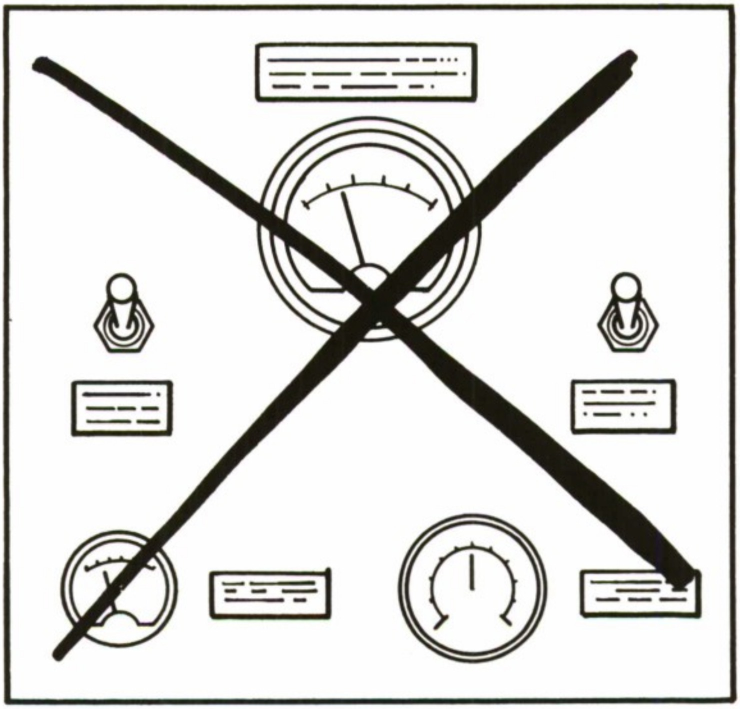


Figure 28. Make Label Position Consistent.

3. STYLE AND SIZE OF PRINT.

a. For short labels use all capital letters in preference to lower case.

Where labels contain several long lines of printing, use caps and lower case letters, restricting all capitals, bold face and italics to short sentences requiring emphasis, such as emergency instructions.

b. Use ARMY-NAVY Standard AND 10400, LeRoy, or similar commercial print types or labels.

(1) If there is possibility that labels will have to be read under conditions of low illumination, (and assuming a reading distance of 28 inches) letter height should be at least 0.20 inch.

(2) Where a label is not a critical one, or if illumination level will always be above one footcandle, letter height of 0.10 inch is satisfactory.

(3) Stroke-width to height ratio should be 1:6 to 1:8.

(4) Letter-width to height ratio should be 3 to 5 except for the "I" which should be narrower and the "M" and "W" which should be wider.

(5) Provide ample margin around lettering.

(6) A margin of ½ letter height is recommended but a minimum of at least 1 stroke width is required.

4. CONTRAST

a. When labels will be read under good lighting conditions, provide maximum contrast.

Under low illumination contrast should be less than maximum.

b. Where dark adaptation is a requirement, letters should be white on a dark background. If dark adaptation is not required, make letters black on a white background.

(1) When white letters are used with a black background, letter-width should be approximately equal to letter-height.

(2) Under special circumstances, (such as emergency and special markings) red and/or yellow letters may be used with a dark background, keeping in mind that if red lighting is used colors will lose their identity.

SECTION C. CODING OF CONTROLS AND DISPLAYS

> Code information only when necessary to avoid operator confusion and reduce possibility of error. Make codes as simple and common as possible. Use shape, size, or color coding or code by grouping of controls and displays.

1. SHAPE AND SIZE CODING

a. When controls may be operated by touch alone they should be coded by shape or size.

(1) When the number of controls to be coded exceeds three, use shape coding in preference to size coding.

(2) Use size coding when only two or three controls are involved.

(3) Size and shape coding may be used in combination, since ability to discriminate shape is relatively independent of size discrimination.

(4) Avoid shape and size coding if operator may be wearing thick gloves.

b. In shape coding select shapes which can be easily identified.

(1) Use functional shapes which suggest the purpose of the control.

(2) Use standardized shapes wherever possible.

(3) Make all shapes used in a particular application sufficiently different from each other to avoid confusion. As a minimum test of adequacy, do not use any combination of shapes which cannot be readily discriminated visually.

(4) Make all controls used for a similar purpose or function of the same shape.

(5) When equipment is such that operators distinguish geometric forms by touch alone, the forms must have a main dimension of at least 12 to 15 mm. (.47 to .58 inches).

c. In shape coding hand controls, specify shape which is comfortable and provides for adequate grasping, especially where large forces must be exerted. Take into consideration the type of gloves operator may be wearing.

Do not permit sharp edges or corners where rapid or forceful actions are anticipated.

d. When displays and controls will always be discriminated visually, size coding may be effective.

(1) Place instruments or controls near each other to facilitate comparison.

(2) When visual comparison is possible, more than three sizes may be used.

e. For specific types of controls, consider the following recommendations:

(1) Shape coding is recommended when a group of rotary controls on a single panel are used for widely different functions.

(2) Levers in proximity to each other and not readily discriminable from each other should have shape coded handles.

(3) Shape coding is ordinarily not recommended for electronics control knobs since manipulation is hampered and discriminability confused when the knob is inverted.

(4) All four right hand fingers can be used to discriminate tactually geometric forms on push buttons. When geometric forms or figures are placed on push buttons for tactual perceiving, make the required pressure 3 ounces or less .

2. COLOR CODING

a. When color coding controls and displays, the pattern should be consistent with regard to function.

(1) Use the same color coding for various components of a unit, for various units of a sub-system, and for the various sub-systems of a system.

(2) Keep the meaning of a particular color consistent throughout a prime equipment.

(3) Give the fewest possible meanings to each color.

(4) Try to make the meanings attached to colors congruent with common usage and existing standards. Use red for STOP for example.

b. Consider human abilities for color discrimination.

(1) Approximately 11 or 12 colors are clearly distinguishable in the visible spectrum, but 5 or 6 is the maximum recommended for use at one time when immediate discrimination is desired. White, yellow, orange, red, blue, and green are most readily distinguished from each other under daylight conditions.

(2) Colors seen by reflected light may lose their identity at low levels of illumination or under colored lighting conditions.

(3) Color coding is effective only if the colors used provide ample contrast with the background.

(4) Use caution in color coding if there is a possibility that color blind individuals may use the equipment. However, color deficient individuals can easily discriminate among black, white, yellow, and blue.

c. Color coding is most effective when combined with other coding methods.

Use combination of color and shape coding to reduce likelihood of error.

d. Scales may be color coded to convey the following types of information:

(1) Desirable operating range. Correct range should be shown by a green sector.

(2) Dangerous operating level. Use red color.

(3) Caution. Amber or yellow may be used.

(4) Undesirable or inefficient ranges. Range should be marked in red.

3. CODING BY GROUPING AND SPACING

a. When coding controls and displays by grouping, group them on the basis of similarity of function or by sequence of use and, insofar as practicable, maintain a similar orientation of related indicators.

b. Use location coding for selection of "blind" controls.

Space controls far enough apart to establish a position habit pattern.

c. Controls to be located "blind" should be forward and slightly below shoulder height.

(1) For controls or control groups in front of or immediately above the operator, arrange them in horizontal rows and 6 to 8 inches aprat.

(2) Place controls which are mounted at side or back of operator 12 to 16 inches apart.

SECTION D. EMERGENCY CONTROLS AND DISPLAYS

Design equipment so that responses made in emergency situations are brief, discrete, and simple; able to utilize the force of gravity, and fit normal response habit patterns.

1. USE CONTROLS WHICH CAN BE QUICKLY ACTIVATED AND EASILY IDENTIFIED BOTH VISUALLY AND NON-VISUALLY.

a. Both push buttons and toggle switches fulfill this requirement. Push button controls

have the additional advantage that control and display can be integrated in back lighted legend push buttons.

b. The choice between push buttons and toggle switches will usually be dictated by over-all panel design considerations. For example, if normal controls are mainly push buttons, it may be wise to use a toggle switch for emergency control.

c. Do not require precise adjustment of emergency controls.

2. DESIGN AND LOCATE CONTROLS TO AVOID INADVERTENT OPERATION

a. Physically separate emergency from normal controls.

Where both emergency and normal controls must be integrated at one location, provide the normal control with an emergency mode or special operating position-add emergency release, going through a detent, exceeding minimum force, etc.

b. If inadvertent activation is a possibility and could result in a dangerous situation, provide the emergency control with easily operated safety clasps or other catches.

c. Place emergency controls so that they will not be activated when operator is reaching for normal controls.

3. DESIGN EMERGENCY DISPLAYS TO TELL THE OPERATOR WHAT TO DO IN AN EMERGENCY.

a. Integrate emergency instructions into the display where possible by use of back lighted legend lights.

b. Assist the operator in associating the emergency display with the emergency control by placing them in close physical proximity.

c. Emergency instructions printed on panels should be printed in all capital letters and should be as short and concise as possible.

4. LOCATE EMERGENCY CONTROLS AND DISPLAYS TO FACILITATE THEIR IDENTIFICATION AND OPERATION.

a. Place emergency displays and controls in optimum positions so they are easily seen and easily accessible for rapid activation.

Where the main panel is overcrowded, emergency controls may be placed overhead to avoid placing them in an otherwise inaccessible location.

b. Place emergency controls within 30 degrees of operator's normal line of sight.

5. MAKE EMERGENCY CONTROLS AND DISPLAYS PHYSICALLY DISTINGUISHABLE FROM NORMAL CONTROLS AND DISPLAYS.

a. Use different types of controls, i.e. toggle switches where normal controls are push buttons.

b. Make emergency controls different sizes than normal controls.

c. Color code emergency controls and displays.

d. If panel contains numerous visual displays, considering using auditory signal for emergency display.

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